Attachment E
Plan for Evaluating SWIFT Soil Aquifer Treatment

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Prepared for

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Acronyms and Abbreviations

AWTP	advanced water treatment plant
BDE	brominated diphenyl ether
CCL	candidate contaminant list
CEC	contaminant of emerging concern
DBP	disinfection by-product
DO	dissolved oxygen
DOC	dissolved organic carbon
EPA	U.S. Environmental Protection Agency
fbg	feet below grade
HAA5	haloacetic acids (monochloroacetic, dichloroacetic, trichloroacetic, monobromoacetic, and dibromoacetic)
HAA	haloacetic acid
HRSD	Hampton Roads Sanitation District
LPA	Lower Potomac aquifer
m^3	cubic meter(s)
MAR	managed aquifer recharge
mgd	million gallon(s) per day
mg/L	milligram(s) per liter
mL	milliliter(s)
mL/min	milliliter(s) per minute
MPA	Middle Potomac aquifer
MPN	most probable number
NDMA	N-Nitrosodimethylamine
ORP	oxidation-reduction potential
PAS	Potomac Aquifer System
pfu	plaque forming unit
PMMoV	pepper mild mottle virus
PVC	polyvinyl chloride
PVFD	polyvinylidene fluoride
RNA	ribonucleic acid
SAT	soil aquifer treatment
SWIFT	Sustainable Water Initiative for Tomorrow
SWIFTRC	SWIFT Research Center

TDS	total dissolved solids
THM	trihalomethane
TKN	total kjeldahl nitrogen
TOC	total organic carbon
UCMR	Unregulated Contaminant Monitoring Rule
UIC	Underground Injection Control
UPA	Upper Potomac aquifer
UVD	Ultraviolet disinfection
WWTP	wastewater treatment plant

SECTION 1

Introduction

1.1 Background

The Hampton Roads Sanitation District (HRSD) Sustainable Water Initiative for Tomorrow (SWIFT) will add multiple advanced water treatment processes to select HRSD wastewater treatment facilities to produce a highly treated water (SWIFT Water) that exceeds drinking water standards and is compatible with the receiving aquifer. Secondary effluent from up to seven of HRSD's existing treatment facilities will be treated at SWIFT facilities and SWIFT Water will be recharged into the Potomac Aquifer System (PAS) to counter depleting aquifer levels. At full-scale, HRSD intends to recharge over 100 million gallons per day (mgd) of SWIFT Water that will significantly reduce the nutrient load to the sensitive Chesapeake Bay and provide significant benefit to the region by limiting saltwater intrusion, reducing land subsidence, and providing a sustainable source of groundwater, a necessity for continued economic expansion in the region.

The SWIFT Research Center (SWIFTRC) involves a nominal 1 mgd advanced treatment facility and injection well located at the Nansemond Treatment Plant (Suffolk, Virginia) that will begin production and recharge in spring 2018. The primary purpose of the SWIFTRC is to demonstrate at a meaningful scale that advanced treatment will produce SWIFT Water that meets primary drinking water standards and is compatible with the groundwater chemistry and minerals composing the PAS. HRSD will collect at least 18 months of operational data to inform and optimize the design and construction and to define permitting requirements for the full-scale SWIFT facilities.

1.2 Purpose

This document is Attachment E within the Underground Injection Control (UIC) Inventory Information Package ("UIC Inventory"). The purpose of this document is to characterize soil aquifer treatment (SAT) through column testing experiments simulating managed aquifer recharge (MAR) operations and describes field scale studies during the operations.

SECTION 2

Bibliography of Previous SAT Studies

2.1 SAT Pathogen Removal

A key consideration for the implementation of indirect potable water reuse is the removal and/or inactivation of pathogens through the advanced treatment process and subsequent aquifer recharge. The SWIFT RC Advanced Water Treatment Plant (AWTP) at Nansemond has been designed to provide log reduction values of viruses, *Cryptosporidium*, and *Giardia* to exceed various regulatory requirements. The purpose of this technical memorandum is to demonstrate that additional pathogen removal credits should be considered for SAT as part of the overall public health protection barriers included in the SWIFTRC AWTP treatment process.

2.1.1 Regulations and Research Supporting SAT Pathogen Removal

California, an early developer of regulations on recycled water, requires 12-log reduction of viruses and 10-log reduction of both *Cryptosporidium* and *Giardia* for potable reuse applications. California regulations published in July of 2015 state that recycled municipal wastewater is credited with 1-log virus removal for each month that the recycled water is in the aquifer up to a 6-log reduction. Prior to aquifer recharge, the recycled water must also meet the definition of filtered wastewater and disinfected tertiary recycled water outlined in the California Regulations. The SWIFT Water at HRSD will meet these criteria. To receive credit for virus reduction in the aquifer, residence time in the aquifer must be validated with a tracer study, starting within three months of AWTP operation. The project sponsor must also:

- Provide documentation of an alternative water source for drinking water well users in case of treatment failure
- Collect at least four water samples, at least one per quarter, from affected aquifers prior to AWTP operation
- Provide a map of the project site including all drinking water and monitoring wells within a two year travel time and including potential future wells
- Provide an engineering report with a hydrogeological assessment of the AWTP setting including properties and extent of affected aquifers, quarterly groundwater elevation contours and calculated flow directions and gradients. Maps and assessments must be based on quarterly evaluations to capture seasonal changes
- Demonstrate treatment processes are operating as intended
- Construct at least two monitoring wells
- Regularly analyze AWTP effluent and monitoring well samples for pathogens, total organic carbon (TOC), nitrogen compounds, contaminants, and chemicals with primary and secondary monochloramines
- Must report failure to meet required pathogen reduction

2.1.2 SAT Pathogen Research

Significant effort has been devoted to studying the effectiveness of SAT for pathogen removal. Studies range from pathogen removal in laboratory columns to full scale field studies at MAR sites. Pathogen removal depends on many factors including travel time in the aquifer, distance travelled in the aquifer,

velocity, aquifer soil texture, microbe type, and water chemistry. Table 2.1 shows that significant virus removal has been demonstrated using SAT in a variety of aquifer and laboratory conditions.

Table 2-1. Summary of SAT Pathogen Studies

Reference	Study	Soil/Aquifer Type	Microbes	Virus Removal
Elkayam et al., 2016	30 years of aquifer recharge in Israel		Fecal coliform, enteroviruses	Fecal coliform: >5-log removal after 17 days, complete removal at reclamation wells (960 day travel time) for 829/831 tests from 1980 to 2012, no detection since 1995 Enteroviruses: complete removal in 54/57 tests (~370 day travel time), no detection since 2001
Verbyla et al., 2016	Two riverbank filtration sites in Bolivia	Riverbank	*E. coli*, *Bacteroides*, coliphage, PMMoV, rotavirus, adenovirus, *Giardia*, *Cryptosporidium*	Log reduction over 65 meters of riverbank filtration: *E. coli*: 3.8, *Bacteroides*: 5.5, coliphage: 2.0, PMMoV: 2.9, rotavirus: >3.5, adenovirus: >3.5, *Giardia*: 2.1, *Cryptosporidium*: 1.7
Sidhu et al., 2015	Diffusion chambers in four Australian aquifer systems	Confined limestone aquifer, unconfined superficial aquifer of iron-coated siliceous sand-carbonated cemented sand, and unconfined quaternary sand and gravel aquifer	Bacterial pathogens, oocysts, enteric viruses	Time for 1-log removal: Bacteria: < 3 days Oocysts: < 120 days Enteric viruses: 18 to > 200 days
Betancourt et al., 2014	Three aquifer recharge systems: Arizona, California, and Colorado	Colorado Riverbank site: alluvial sand with some gravel and silts, SAT sites: and coarse sand/sandy gravel	Adenoviruses, enteroviruses, Aichi virus, PMMoV	Viruses removed below detection limit—log removal quantification difficult: Arizona site: > 3.42-log removal of all viruses in ~14 days California site: > 1.05-log removal of adenovirus and non-detect of other viruses in 0.5-128.5 days Colorado site: >0.7 log removal of adenovirus, > 1.15-log removal of enterovirus, > 2.49-log removal of Aichi virus and > 1.92-log removal of PMMoV in 5 days
Santamaria et al., 2013	In-situ 4 meter x 2.5 meter lysimeter and 2-meter column	Sandy soil	*Cryptosporidium*	5-log removal in 2.4 days in lysimeter; 4-log removal in 0.8 days in 2-meter column
Page et al., 2010	Diffusion chamber in Australian aquifer		Rotavirus, *Cryptosporidium*, *Campylobacter*	Rotavirus: 0.0055-log/day, *Cryptosporidium*: 0.012 log/day, *Campylobacter*: total 5.6-log removal
Fox et al., 2006	Tracer study in California aquifer	Shallow vadose zone aquifer	Bacteriophages	7-log removal in 100 feet of subsurface travel
Hijnen et al. 2005	Laboratory 0.5 meter columns with soil from an	Sandy soil and gravel soil	MS2, *E. coli, C. perfringens, C. parvum, G.*	Sandy aquifer soil (column at 0.5 meter per day): MS2: 3.3, *E. coli*: 4.7, *C. perfringens*: >5, *C.*

Table 2-1. Summary of SAT Pathogen Studies

Reference	Study	Soil/Aquifer Type	Microbes	Virus Removal
	aquifer recharge site and a riverbank filtration site in the Netherlands		*intestinalis*	*parvum*: 3.9, *G. intestinalis*: 6.2 Gravel river aquifer soil (column at 0.9 meter per day): MS2: 3.4, *E. coli*: 4.8, *C. perfringens*: >2.4, *C. parvum*: >6.7, *G. intestinalis*: >7.4
Anders et al., 2004	Tracer study in California aquifer	Fine-coarse sand aquifer	MS2 and PRD1	1998 experiment: 0.37-log units/meter MS2; 0.55-log units/meter PRD1. 2000 experiment: 0.83-log units/meter MS2; 3.0-log units/meter PRD1
Quanrud et al., 2002	WWTP secondary effluent in 1-meter soil columns	River sand or sandy loam	Coliphages and poliovirus	Coliphage: expected 2-log removal in 17.5 hours, 3-log removal in 26 hours
Tufenkji et al., 2002	Several riverbank filtration sites in the Netherlands	Riverbank	Bacteriophages, coliphages, enteric viruses	Average log removal in 15-63 days: RNA bacteriophages: 6.0 Enteric viruses: 4.0 Coliforms: 5.0 Clostridia: 3.3 Fecal streptococci: 3.3

Note:
m = meter(s)
PMMoV = pepper mild mottle virus
RNA = ribonucleic acid
WWTP = wastewater treatment plant

A paper published in 2009 by Liping Pang compiles results from over 150 field and laboratory experiments. Table 2.2 shows average log removal rates per meter for *E. coli*, enterococci, fecal coliforms, fecal streptococci, and *Salmonella* phage bacteria from lysometer studies. Averages include experiments conducted in various locations with various microbial sources and soil types.

Table 2-2. Summary of Lysimeter Studies compiled by Pang, 2009

Microbe	Average Log Removal/Meter
E. coli	0.59
Enterococci	0.53
Fecal coliforms	3.25
Fecal streptococci	4.02
Salmonella phage	2.34

2.2 SAT Organics Removal

Soil column experiments have been used to study the fate and transport of different compounds present in water to be used for aquifer replenishment. The focus of most studies has been on contaminants of emerging concern (CECs). Banzhaf et al. (2012) studied sorption and biodegradation of carbamazepine, sulfamethoxazole and diclofenac. Strauss et al. (2011) and Fan et al. (2011) observed removal mechanisms for sulfamethoxazole and its metabolites. Other CECs that have been considered in soil column experiments are Bisphenol A, 17 β-estradiol, 17 α – ethynyl estradiol (Patterson et al., 2010), primidone, atenolol, meprobamate (Burke et al., 2013), perfluoroalkyl acid (McKenzie et al., 2016) along with dissolved organic carbon (DOC) and organic halide (Quanrud et al., 1996). Few have also looked at the effects of using different electron acceptors (Nay et al., 1999) and substrates (Hebig et al., 2017) on the transport and degradation of these CECs. A summary of relevant papers is available in Table 2.3 below.

Table 2.3. Literature review of soil column studies used to evaluate the attenuation and removal of organics and CECs by SAT.

Title	Citation	Diam (m)	Height (m)	Flow Rate/ velocity (reported)	Flow Rate (mL/min)	Effective Porosity	Velocity (cm/d)	Travel Time(day)	Sampling frequency	Contaminants	Mechanism tested	Comments
Sorption behavior of 20 wastewater originated micropollutants in groundwater - Column experiments with pharmaceutical residues and industrial agents	Burke, et al. (2013). *Journal of contaminant hydrology* , *154* , 29-41.	0.1	0.3	5.6E-9 m3/s	0.336	0.45	13.7	2.19	Conservative tracer: 4 hours Contaminants: 30 hours	Diazepam, Oxazepam, Primidone, PEMA, Atenolol, FAA, AAA, AMPH, Propanolol, Sotalol, Metoprolol, p-TSA, Tolyltriazole, Phenacetine, Methyl-phenacetine	Sorption / Desorption; biological degradation neglected	Column was conditioned with tap water until constant conditions of pH, oxygen and temperature reached. Influent with contaminants and conservative tracer (NaCl) was then passed through column for 5 days. Inflow was switched to tap water and samples taken for 7 days.
Redox sensitivity and mobility of pharmaceutical compounds in a low flow column experiment	Banzhaf, et al. (2012). Science of the Total Environment, 438, 113-121.	0.136	0.351	14.1 mL/h	0.235	0.41	5.7	6.18	Contaminants: collected every 3 hours, every 5th sample was analyzed	Carbamazepine, Sulfamethoxazole, diclofenac	Sorption and degradation	Conditioning period with nonspiked water - 2.5 months. Concentration tested in the range of 175 - 852 ng/L. Influent was spiked with the contaminants. The aim was to test the Influence of nitrate concentration on breakthrough behavior. CXTFIT code was used for hydraulic modeling. Result: Carbamazepine seemed degradable when fraction of organic carbon (foc) of sediment was high. Silfamethoxazole is sensitive to nitrate reducing redox conditions.
Guidelining protocol for soil column experiments assessing fate and transport of trace organics	Oriol Gibert , Marta Hernández Amphos 21: Ester Vilanova, Ona Cornellà	0.1-0.2	1.5 - 2.5	not reported	not reported	Not reported	not reported	not reported	not reported	not reported	not reported	Guideline/Review
Fate of organics during column studies of soil aquifer treatment	Quanrud, et al. (1996). Journal of Environmental Engineering, 122(4), 314-321.	0.0826	1.00	200 ml/h in wet cycle	3.33 in wet cycle	0.46	194.5	0.51	not reported	DOC, adsorbable organic halide	sorption, microbial degradation	Columns were subjected to alternating wet and dry cycles each of 7 days. Unsaturated conditions. Result: DOC was removed by biodegradation, AOX was removed by sorption.
Use of column experiments to investigate the fate of organic micropollutants - review	Banzhaf, S. (2016). Hydrology and Earth System Sciences, 20(9), 3719.	0.02 - 0.36	0.05 - 2.4	not reported	not reported	not reported	4 - 348 cm/d (velocity)	0.7 - 1.25	not reported	not reported	not reported	**Review Paper**
Do Pharmaceuticals, Pathogens and other organic waste water componds persist when wastewater is used for recharge?	Cordy, et al. (2004).. *Groundwater Monitoring & Remediation* , *24* (2), 58-69.	0.325	2.1	5.3 cm/d (q=Q/A)	3.1	0.38	13.9	15.06	not reported	vet and human antibiotics prescription drugs, nonprescription drugs, household and industrial chemicals, steroids and reproductive hormones	not reported	Experiment designed to approximate recharge conditions similar to those of a wetting cycle in recharge spreading basin. 200 L of secondary effluent discharged on the surface and allowed to infiltrate. The effluent from the SAT columns are tested for contaminants to check their persistence.
Sorption and biodegradation of organic micropollutants during river bank filtration; A laboratory column study	Bertelkamp, et al. (2014). Water Research, 52, 231-241.	0.36	1.00	v=2.4-3.2 m/d	not reported	0.31-0.42	240-320	0.31-0.42	influent and effluent measured at 6 different time periods in a month (10 h, 34 h, 58.5 h, 80 h, 1 wk, 4 hrs)	ibuprofen, ketoprofen, gemfibrozil, acetaminophen, trimethoprim, caffeine, propranolol, metoprolol, atrazin, carbamazepine, phenytoin, sulfamethoxazole, hydrochlorothiazide, linomycin	sorption and bio-degradation	Aim of the study was to obseve if physico-chemical parameters such as hydrophobicity, charge and molecular weight affected biodegradation rates. Columns were fed with surface water from local canal; Adaptation period of 4 months.
Effects of pH and manure on transport of sulfonamide antibiotics in soil	Strauss, et al. (2011). *Journal of environmental quality* , *40* (5), 1652-1660.	0.052	0.3	0.2 ml/min - before reaching saturation point; 1.44 ml/min after saturation ; Darcy velocity - 4 cm/h	0.2 - before reaching saturation point; 1.44 after saturation	0.38-0.40	248.0	0.12	not reported	sulfamethoxazole, sulfamethazine, sulfadimethoxine	not reported	Aim of the study was to test the hypothesis that manure as cosolute and pH influence sulfonamide transport. Breakthrough curves of tracer and sulfonamides at different pHs was modeled using Hydrus 1-D.
Sorption, fate and mobility of sulfonamides in soils	Fan, et al. (2011). Water, Air, & Soil Pollution, 218(1-4), 49-61.	0.084	0.15	19.8-39.5 cm/h	constant head tank used for constant downward flow. Flow rate not mentioned.	Not reported	480-960	0.029-0.036	column effluent collected every 2 mins.	sulfonamides	sorption	In order to describe the fate and transport of Sulfamethazine (SMZ) and its metabolite under steady-state flow in a homogeneous soil, a two-site chemical nonequilibrium transport model was used. Duration of column experiment: 6 h. soil extracts from column analyzed to analyze sorption affinity. Result: SMZ had low sorption affinity and all sorption was reversible.
Transport of primidone, carbamazepine, and sulfamethoxazone in hermally treated sediments-lab column experiments	Müller,et atl. (2013). Journal of Soils and Sediments, 13(5), 953-965.	0.135	0.35	1.0-1.3 ml/min for four different column experiments	1.0 - 1.3 for four different column experiments	32% of vol (0.32)	28.8-37.4	0.93-1.22	total of 20 samples of effluent collected per test. sample collected every hour. Sample volume - 75 ml	carbamazepine, sulfamethoxazole, primidone	degradation, sorption	Column study: 4 column expriments (untreated sediment, pretreated sediment at different temperatures) Results: all three compounds showed similar transport behavior of conservative tracer. Carbamazepine and Primidone are retarded in the presence of organic matter. Order of decreasing retardation CBZ>PMD>SMX
Fate of nine recycled water trace organic contaminants and metal(oids) during managed aquifer recharge into a anaerobic aquifer: column studies	Patterson, et al. (2010).Water research, 44(5), 1471-1481.	0.145	2.00	360 ml/day; velocity - 5.2 cm/day	0.25	0.42	5.2	38.46	not reported	Bisphenol A, 17 b estradiol, 17 a -ethynylestradiol, carbamazepine, N-nitrosomorpholine, iohexol	retardation, degradation	Setup: 17 sampling ports along the column; Influent is RO treated water. Results: Anaerobic consitions were good for the degradation of bisphenol, estradiol, ethynylestradiol. Carbamazepine, oxazepam did not degrade readily.
Transport of Pharmaceutically Active Compounds in Saturated Lab Columns	Scheytt, et al. (2004).\ Ground Water, 42(5), 767-773.	0.14	0.35	5.9 x 10^-5 m3/hour velocity - 0.3 m/d; specific discharge - 0.097 m/day	0.98	0.32	30.0	1.17	Sample volume - 25 ml; pH, temp, O2 and saturation measured every 10 mins,	clofibric acid, propyphenazone, diclofenac	degradation, sorption	The aim of the study was to study transport behavior of contaminants.The equilibration time 5 days; influent with tracer and PPCPs was passed through the column for 10 days; Column flushed for 5 days
Transport behavior of the pharmaceutical compounds carbamazepine, sulfamethoxazole, gemfibrozil, ibuprofen, and naproxen, and the lifestyle drug caffeine, in saturated laboratory columns	Hebig, et al. (2017). Science of The Total Environment, 590, 708-719.	0.076	0.41	not reported	0.095	0.27-0.33	10.0	4.10	68 samples collected at intervals varying between 5 and 230 h	Naproxen, Gemfibrozil, Ibuprofen, caffeine, sulfamethoxazole, carbamazepine	retardation, degradation	Objective: Study the effect of substrates on the transport of micropollutants. Three columns used: iron clad sand, organic carbon sand, long point sediment; Breakthrough curves of compounds plotted. CXTFITT model used to determine Retardation factor, Dispersivity. Result: Sulfamethoxazole removed due to redox activity, Presence of organic carbon increases retardation of compounds
Effects of Chemical Oxidants on Perfluoroalkyl Acid Transport in One-Dimensional Porous Media Columns	McKenzie et al. (2015) ES&T, 49, 1681-1689	0.025	0.08	v=83.4 cm/d	0.085	0.48	83.4	0.10	PFAA : 18-27 samples collected per column per phase; pH samples: 6-7 samples per column per phase; TOC: 3 samples per column per phase; Metals: 3 samples per column per phase	perfluoroalkyl acid (PFAs)	sorption, degradation,	Columns were loaded with (11) perfluoroalkyl acids (PFAAs) amounting to ~30 pore volumes. Chemical oxidants (permanganate and activated persulfate) were added later to evaluate mass/concentration reduction
Fate and behavior of organic compounds in an artificial saturated subsoil under controlled redox conditions: The sequential soil column system	Nay et al. (1999) Biodegradation, 10, 75-82	0.025	0.16	Q=60mL/d	0.0417	Not reported	40.7	0.39	recovery time of about 12 h between single samples and a minimum recovery time of 5 days undisturbed operation were allowed between sample series	perchloroethene, 1,1-dichloroethene, 1,4-dichlorobenzene, 2,4-dichlorophenol, 2-nitrophenol, benzene, toluene, naphthalene	redox, biodegradation,	Sequential Columns (4) - Travel Time through system ~ 1.5 d; Electron acceptors varied in each column (CO2, SO4, NO3, and O2). Chlorinated VOCs and non-chlor VOCs added in solution. Column experiments were conducted in phases (i) first sorption (ii) pulse oxidation (iii) extended oxidation (iv) first desorption (v) second sorption (vi) second desorption

2.3 Use of Soil Column Studies for SAT Investigations

Column set up, dimensions and operational procedures vary widely among different experimental studies. The diameters of the columns reported in literature range from 0.02 – 0.36 meters and the lengths are in the range of 0.05 – 2.4 meters (Banzhaf et al., 2016). In order to prevent preferential flow paths or sidewall flows, a diameter to length ratio of 1:4 is recommended (Gibert et al., 2015). The flow rate through the columns has varied from 0.04 milliliter per minute (mL/min) (Nay et al., 1999) to 3.33 mL/min (Quanrud et al., 1996), flow rates were chosen based on the desired travel times to be simulated. The column casings are commonly made up of materials such as stainless steel, glass and transparent polyvinyl chloride (PVC). Peristaltic pumps have been typically used to mechanize a pressurized upflow to let the influent move up the column. Upflow is preferred, particularly for saturated soil column tests, as it allows air bubbles to escape from the top. Packed soil columns are preferred over monoliths, which are undisturbed soil columns extracted from site, in column studies. Packed soil columns ensure homogeneity and can be constructed with bulk density similar to the natural site conditions (Lewis et al., 2010). After the construction of the soil columns and before beginning the experiment, columns are allowed to stabilize which is done by flushing with uncontaminated and/or non-spiked water. This adaptation period has been reported to be anywhere from 5 days (Scheytt et al., 2004) to 4 months (Bertelkamp et al., 2014). A conservative tracer is passed through the column. Tracer is a non-reactive compound that is not subject to sorption or biotic/abiotic transformation and is used to determine the boundary and initial conditions of the soil column (Lewis et al., 2010). Bromide is the most commonly used conservative tracer. Sodium Chloride and Lithium Chloride are other compounds that have been used for tracer tests (Burke et al., 2013; Schyett et al., 2004).

Feed water with the contaminants of interest is passed through the column and samples of the column effluent collected for analysis. Pumped feed water flow rate is used to control hydraulic retention time within the SAT column. The effluent concentrations are typically plotted against time or pore volume to produce a breakthrough curve and compared to the breakthrough curve of conservative tracer to detect any differences in their transport behavior. Numerical modeling has also been used in various studies to estimate parameters such as retardation factor, rate of biodegradation, and dispersivity of compounds. PHREEQC, CXTFIT and HYDRUS-1D are some of the software that are available and are applicable for modeling of one dimensional flow characteristics (Gibert et al., 2015). Muller et al. (2013) used CXTFIT to produce breakthrough curves of carabamazepine, primidone and sulfamethoxazole and determine the transport behavior of the compounds. The retardation of Carbamazepine and primidone were observed to increase in the presence of organic matter while sulfamethoxazole was the least removed compound among the three. On the other hand, Hebig et al.'s (2017) study shows that sulfamethoxazole gets removed in redox reactions. Hebig et al. used CXTFIT model to estimate retardation factors and dispersivity of sulfamethoxazole, ibuprofen, and other CECs. Soil column studies, therefore, provide meaningful information regarding the transport and degradation behaviors of compounds and the conditions under which their removal can be optimized. These considerations are significant for the full-scale implementation of managed aquifer replenishment.

SECTION 3

Soil Column Testing

3.1 Project Introduction and Objectives

Soil column testing was used to evaluate and quantify the benefit of SAT in terms of pathogens, organics and CECs, disinfection by-products (DPBs), and nitrogen species. Phase I involved constructing four soil columns within the SWIFT Pilot facility at the HRSD York River Treatment Plant. The soil columns were fed pilot effluent (Ultraviolet disinfection effluent) from the SWIFT advanced treatment pilot facility. Subject to the results from Phase I, Phase II work will involve continued soil column work located at the SWIFTRC and fed SWIFT Water from the demonstration process.

The specific objectives of the soil column work included the following:

- Evaluate the removal of pathogens and pathogen indicators by SAT, with specific focus on confirming at least 1 log removal of viruses, *Cryptosporidium*, and *Giardia* per month of aquifer travel time.
- Evaluate the attenuation and removal of organic contaminants through SAT, focusing on CECs and TOC and DOC.
- Evaluate the production of DBPs, including trihalomethanes (THMs), haloacetic acids (HAAs), and N-Nitrosodimethylamine (NDMA), as a result of free chlorine or monochloramine injection upstream of the SWIFTRC injection well (TW-1), evaluate the dissipation of free or combined chlorine residual in the soil column, and evaluate the removal of DBPs through SAT.
- Evaluate the attenuation, transformation, and removal of nitrogen species by SAT

Two different travel times were considered as part of Phase 1. One set of two soil columns were used to simulate the monitoring well (MW-SAT) that will be located at the SWIFTRC at a distance of approximately 50 feet from the injection well (TW 1), and these columns are referred to here as the "50-foot" columns. A travel time of 3.2 days was simulated in these columns, based on that estimated using the approach described below:

- Injection at TW 1 was simulated at 1.0 mgd with the flow split between the Lower Potomac aquifer (LPA), Middle Potomac aquifer (MPA), and Upper Potomac aquifer (UPA) based on the expected transmissivities and hydraulic conductivities of each aquifer zone. The flow directed to the UPA was estimated to be 0.42 mgd.
- This flow rate was then used with the screen length in the UPA and an estimated effective porosity of 0.35 to determine the radial velocity of the injected water as a function of distance from TW 1 using a Lagrangian calculation approach.
- This gives 3.2 days travel time in the UPA. Using the same porosity, the soil columns were designed with a feed flow rate of 13 mL/min, a diameter of 12 inches, and soil depth of 7.5 feet.

The other set of two soil columns were used to simulate a somewhat arbitrary travel time of 1 month, and these columns are referred to here as the "1-month" columns. The target feed flow rate was estimated at 2.2 mL/min using the expected aquifer porosity for soil columns with a diameter of 12 inches and a soil depth of 12 feet.

The feed for one of each set of soil columns will be amended with free chlorine and the other with preformed monochloramine, followed by 5 minutes of contact time in the feed tubing, and injection in to the bottom of the columns. The objective is to simulate the two different conditions possible at the SWIFTRC and DBP formation and removal per the objective described above.

The soil columns were filled with washed aquifer sand material, compacted to remove entrapped air, and then flushed with pilot effluent per protocols developed as part of similar projects. A tracer study was conducted to confirm travel time and tracer dispersion in the column. The columns have been in continuous operation for at least four months. Pathogen removal was assessed by amending the column feed with MS2 coliphage, non-pathogenic *E.coli* K12, and fluorescent microspheres simulating *Cryptosporidium* oospores. Sampling and analysis will be initiated per the plan detailed below to consider nitrogen species, TOC and DOC, CECs, and DBPs. The sampling schedule will be conducted in such a way that the column influent and effluent samples can be compared in the context of the measured travel time for each set of soil columns.

It is important to recognize that for these soil columns, it is not possible to assess hydraulics limitations due to clay mineral fragmentation. This is because the soil used in the column represents well-washed aquifer sands removed from the PAS during monitoring well installation. This washing step was designed to remove well drilling mud contamination, and this effectively removed most of the clay material. Furthermore, it is not possible to extract a truly representative core from the aquifer that would be of a size sufficient to simulate the travel times being considered here.

The dissolved oxygen (DO) concentration of the pilot effluent should be in the range of 15 to 20 milligrams per liter (mg/L) as a result of ozonating water in the upstream treatment process. Efforts were made to prevent contact of the feed water with the atmosphere to prevent stripping of oxygen, and DO probes were mounted in the top of the columns to attempt to measure the DO at the soil column effluent. Temperature is another important parameter for the soil column study. In order to track any effect of temperature on the fate and transport of contaminants or pathogens, DO probes with the ability to take temperature measurements were installed to monitor the temperature of the effluent from the columns. The slow rate of the flow of influent into the columns allowed the water to reach ambient temperature. Therefore, the ambient temperature was monitored through an online temperature sensor which was placed onto the soil column frames. The probes were connected to a programmable logic controller (PLC) to allow for continuous logging of temperature measurements.

Redox conditions were not actively controlled in the soil columns, but DO transport through the columns will be known, and oxidation-reduction potential (ORP) measurements will also be made. This is an important consideration for removal and degradation of organics. However, given the removal of clays from the soil column material, the inability to completely control redox, and the lack of interaction with native groundwater, another limitation of the soil column study is that it is not possible to evaluate the oxidation of reduced iron and mobilization of metals such as manganese and arsenic. As indicated above, this must be evaluated using the SWIFTRC network of monitoring wells.

It is likely that Phase II soil column work will consider travel times in excess of 1 month, perhaps up to as long as 18 months. Phase II is described in Section 3.6 below.

3.2 Phase I - Experimental Setup

The system is housed in the SWIFT pilot facility at the York River Treatment Plant at room temperature. The construction of Phase 1 soil columns for HRSD's SWIFT Pilot Program consists of two travel time intervals. As shown on Figure 3.1 two columns were constructed to represent the travel time of replenished water to the monitoring well 50-feet (MW-SAT) from the injection well head (TW-1), and two other columns to represent 1 month (30 days) of aquifer travel time after the water is added to the aquifer. The columns run in parallel to allow for replication of experiments in real time, however one column for each travel time will be fed with free chlorine and one will be fed with monochloramine to simulate the 5-min contact time chlorine contact pipe associated with the SWIFTRC (as described above)

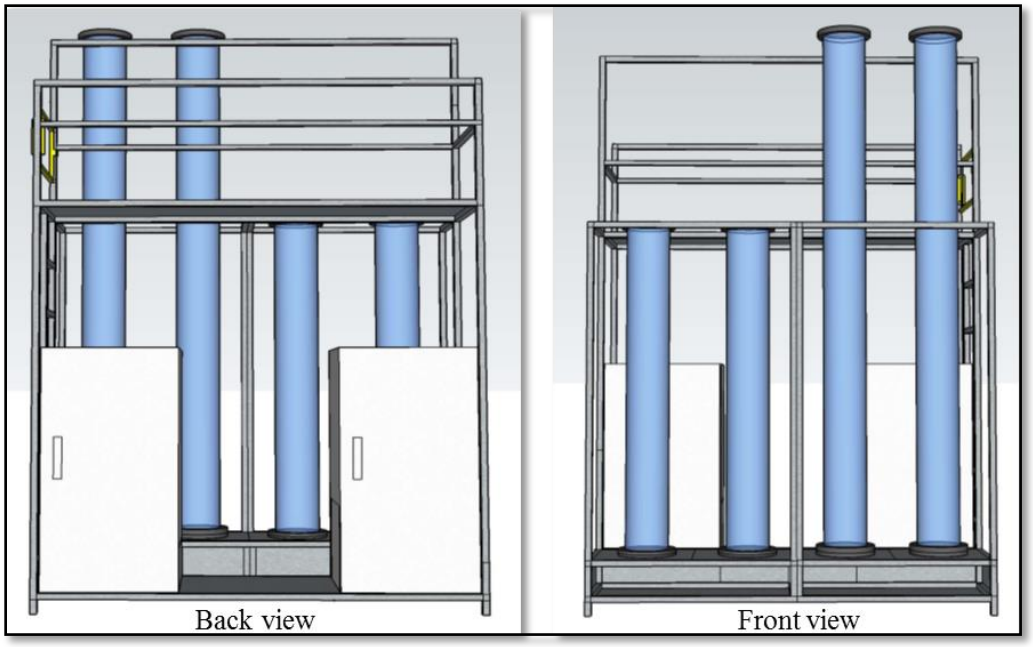


Figure 3-1. SAT Columns Schematic

The diameter of all four columns is 1 foot. The columns that represent 50 feet of the travel from the well head to the monitoring well are 8-feet in length, filled with 7.5-feet of soil. The columns that represent 1-month of aquifer travel time are 13 feet in length, filled with 12 feet of soil. Influent are stored in a refrigerator in a 7-gallon container. The 50-foot columns and the 1-month columns are being fed with parallel precision peristaltic pumps, an upflow configuration at a rate of 13 mL/min and 2.2 mL/min, respectively.

DO probes were installed at the top of each column in a flange face that allow for real time DO measurement. Effluent travels through the top of the column, through a fitting out of the flange face into a sample refrigerator. The columns were constructed from 12-inch schedule-40 clear PVC. Clear PVC was used to ensure all air bubbles were removed from the column during soil filling and flushing. Upon the start of the sampling campaigns, the columns were covered with thick polyethylene plastic with the thickness of … to prevent light penetration that might encourage algal growth or photolytic chemical transformations not representative in the aquifer. The soil used to fill the columns was washed sand from the Potomac aquifer that was removed during the drilling and construction of the monitoring wells at the SWIFTRC.

3.3 Phase I – Soil Column Operation

The SAT columns are being operated on a continuous basis. As shown on Figure 3-2 highly treated water coming from the UVD system is the feed for the SAT columns (SWIFT Pilot Effluent).

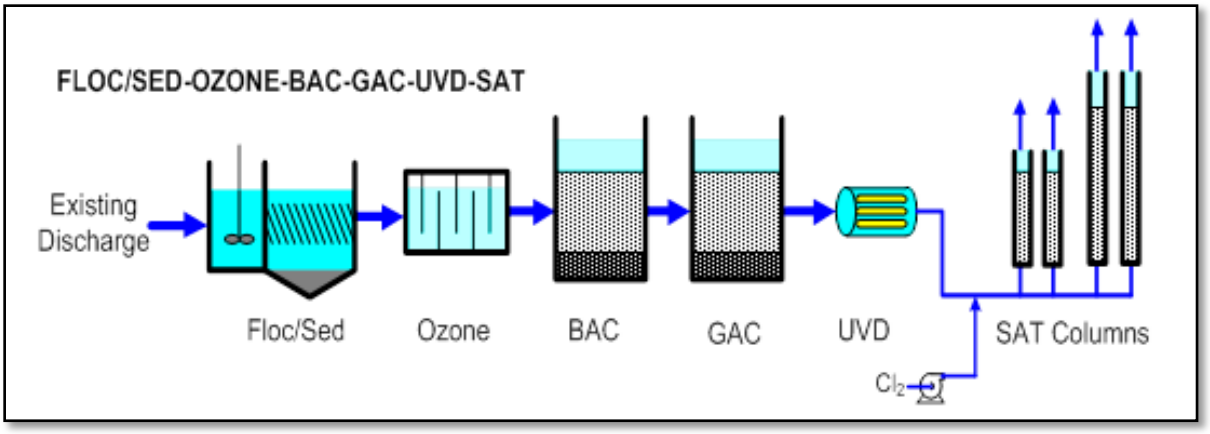


Figure 3-2 SWIFT Pilot Treatment Process

For the 50-feet design SAT column, a total daily volume of 18 L is necessary to continuously feed 13 mL/min, and for the 1-month design SAT column, a total daily volume of 3.1 L is necessary to continuously feed 2.2 mL/min. The UVD system does not operate continuously due to flowrate restrictions, so feeding of the soil columns is accomplished by filling on a daily basis four 7-gallon containers with UVD effluent. As shown on Figure 3-3**,** the containers with UVD effluent are stored in a refrigerator. Additionally, there are four 5-gallon cubitainers collecting the effluent from each SAT column. All tubing related with the SAT system is replaced at a regular time interval or in the event that biofilm appears. The pumps are calibrated at least twice per week.

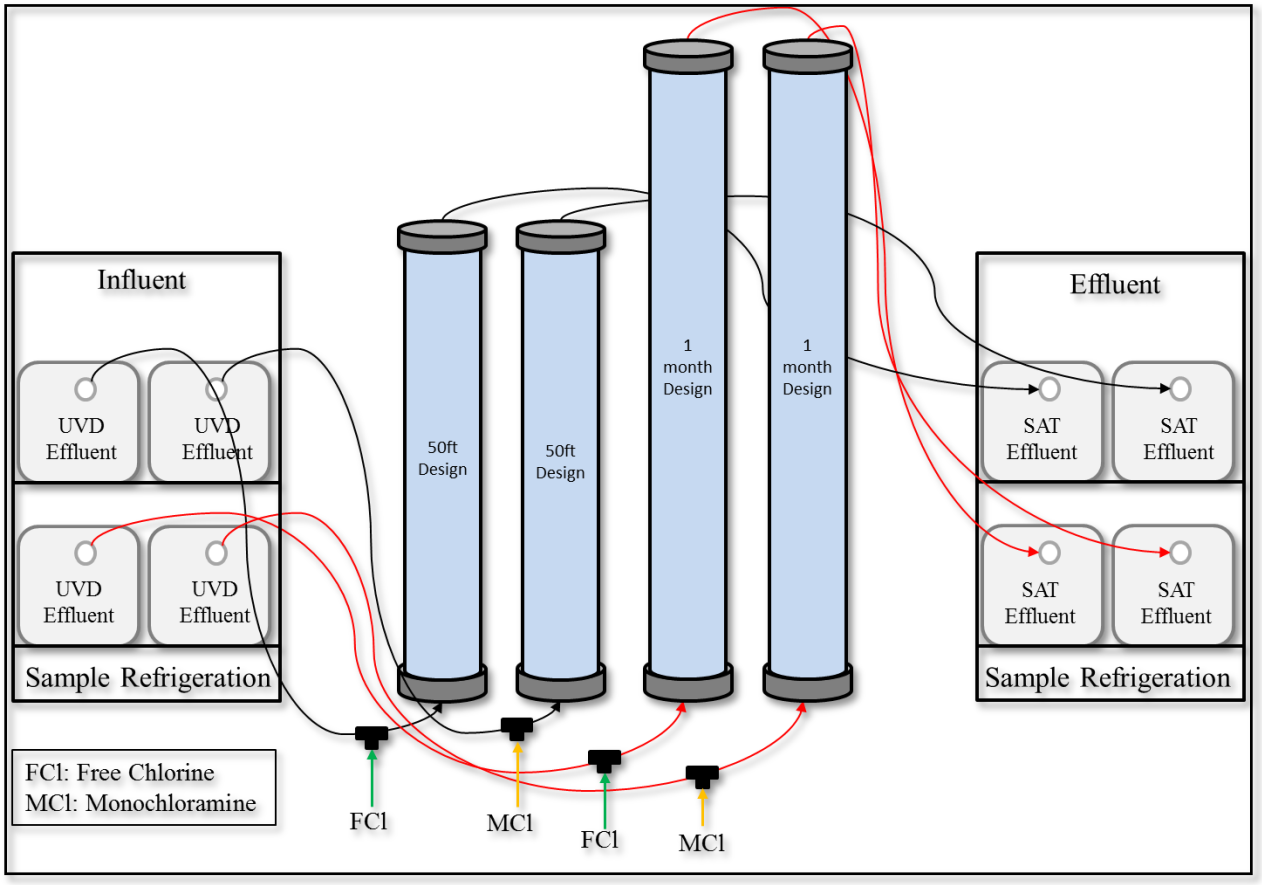


Figure 3-3. SAT Columns Sampling Configuration

The SWIFTRC was designed to have the capability to either feed free chlorine or monochloramines before recharging the aquifer to avoid biofouling in the well and to achieve virus disinfection credit when using free chlorine and the 5-minute chlorine contact pipeline associated with the SWIFTRC. For Phase 1 soil column work, these two different approaches will be tested to better understand the potential of forming DBPs in the aquifer, followed by removal of DBPs through SAT. Free chlorine or monochloramines will be injected into the feed tubing using precision peristaltic pumps to achieve doses expected at the SWIFTRC and a total of 6-minutes of contact time in the tubing prior to entry of the flow into the soil columns.

Once all SAT columns were ready for operation, soil collected from the Potomac aquifer was washed and sieved to remove material larger than ~4 mm before loading it into the columns. Sieving the soil was done to minimize short-circuiting and flow distortions caused by large debris. As the soil was added to the column, pilot effluent from the SWIFT pilot was added to saturate the soil, and the columns were tapped with a rubber mallet to improve compaction and release trapped air. Sieve analysis was also conducted on the washed sand to determine the media size distribution. The sand was sent to ECS Mid-Atlantic for three sets of sieve analyses.

After obtaining the desired level of soil in the columns, the flushing period started. Flushing was accomplished by pumping SWIFT pilot effluent into the bottom of each column at a higher flowrate (higher than the designed flowrate). Flushing details have been described below:

- Design #1 (50-feet) was run at 3X the designed flow rate for more than 20 bed volumes.
- Design #2 (1-month) was run at 3X the designed flow rate for more than 3 bed volumes.

After the flushing period was completed; a tracer study was performed on each column using an input of sodium chloride continuously over the duration of a few days to confirm the retention time within the columns. Prior to the introduction of tracer, the background concentration of chloride in the influent was analyzed to determine the amount of chloride to be added. During the tracer study, the SAT columns were operated at the design feed flow rates. Effluent samples were collected for chloride analysis ahead of, during, and after the expected passing of the chloride concentration front for each of the four columns, until the chloride concentration decreased to within 10% of the background value. The tracer test was conducted first on the 50-foot columns. The tracer data was used to assess the actual travel time and the chloride dispersion coefficient by fitting the data to a 1D conservative transport model equation. The dispersion coefficient and effective porosity observed were then used as a guide to conduct tracer test on the 1 month columns. The feed flow rates were adjusted based on the results from tracer testing.

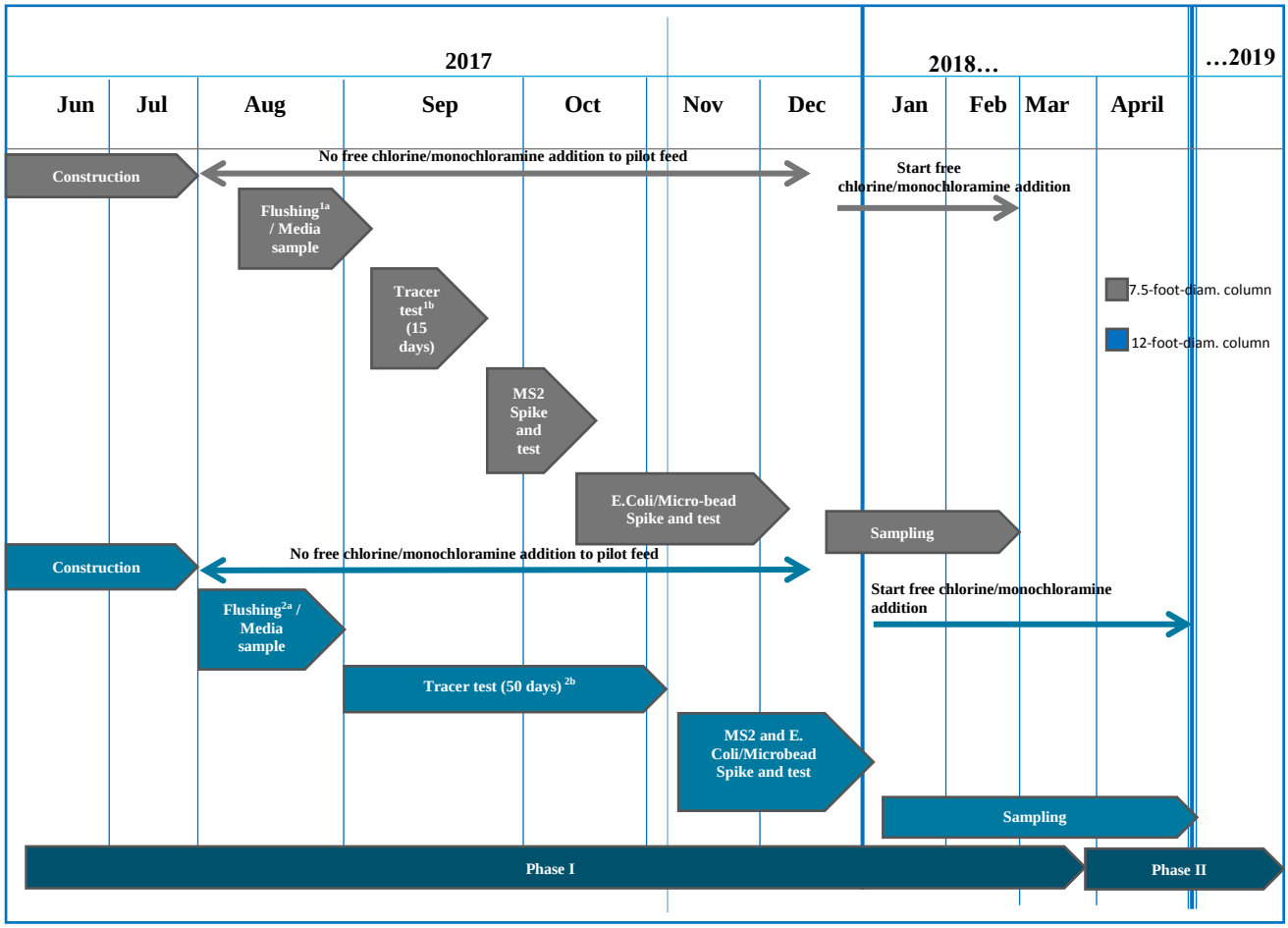
Once flow conditions were set and SAT columns were fully operational, microbial challenge testing began. The pathogen and pathogen indicator concentrations in the SWIFT Pilot effluent are consistently below detection, and so challenge testing was the only viable method for evaluating pathogen removal by SAT. MS2 coliphage, non-pathogenic E.coli strain and fluorescent microspheres (substituting inactivated *Cryptosporidium* oospores) were used to spike the feed of the SAT columns. Fluorescent microspheres are similar to the *Cryptosporidium oo*cysts in molecular size and are less adsorptive. These microspheres provide advantages over inactivated (irradiated) *Cryptosporidium* oocysts in SAT studies. In demonstrating system performance fluorescent microspheres provide conservative log removals over oocysts. While oocysts (negative surface charge) are removed via physical mechanisms and physicochemical filtration, comparable sized microspheres will be removed by physical mechanisms only. Fluorescent microspheres used by HRSD do not have a net surface charge. Inactivated *Cryptosporidium* oocysts could potentially have different surface charge characteristics from live oocysts depending on the inactivation process which may affect removal as well. So while inactivated oocysts may seem ideal from a health risk perspective, high cost make them impractical. Finally commercial fluorescent microspheres allow high enough concentrations to measure significant removal over several

orders of magnitude. Oocysts are naturally lower in concentration than other pathogens (bacterial and viral) so achieving a desirable seed stock concentration to quantify SAT removal was not practical.

Sampling and analysis will be initiated per the plan described below.

3.4 Phase I – Schedule

The SAT columns will be operated in 2 different phases. Phase 1 is taking place at the SWIFT Pilot located at the HRSD York River Treatment Plant, and Phase 2 will take place at the SWIFTRC located at the Nansemond Treatment Plant. The Phase I project schedule is shown in Figure 3-4.



[1a] Flushing more than 20 pore volumes at 3X flow rate. Anticipated duration 21 days; [1b] Tracer injected continuously for 4 days. Testing for tracer conducted for 15 days from the point of tracer injection.

[2a] Flushing more than 3 pore volumes at 3X flow rate. Anticipated duration 30 days; [2b] Tracer injected continuously for 10 days. Testing for tracer conducted for 50 days from the point of tracer injection.

Figure 3-4. Schedule of the SAT Columns study

Table 3-1. Duration, flow rates and pore volumes required for tests in 50-foot columns
50-foot Column (Total Volume = 0.167 cubic meter [m^3]); Estimated Pore Volume = 0.058 m^3 = 58,371 milliliters [mL])

Experimental Phase	Duration (d)	Q (mL/min)	Pore Volumes	Daily Solution Volume (mL)
Flushing	22	39	21.1	56,160
Tracer Injection Duration	4	13	3.1	18,720
Tracer Test Sampling	15	13	4.7	18,720
MS2 Injection Duration	5	13	1.6	18,720
MS2 Sampling	20	13	9.4	18,720
E.coli and Micro-bead Injection	5	13	1.6	18,720
E.coli and Micro-bead Sampling	20	13	6.2	18,720
Monitoring	135	13	42.2	18,720

Table 3-2. Duration, flow rates and pore volumes required for tests in 1-month columns
1-month Column (Total Volume = 0.267 m^3; Estimated Pore Volume = 0.093 m^3 = 93,394 mL)

Experimental Phase	Duration (d)	Q (mL/min)	Pore Volumes	Daily Solution Volume (mL)
Flushing	40	6.6	3.1	9,504
Tracer Injection Duration	10	2.2	0.33	3168
Tracer Test	50	2.2	1.7	3,168
MS2/*E. coli* and Micro-bead Spike	30	2.2	3.6	3,168
MS2/*E.coli* and Micro-bead Sampling	50	2.2	1.7	3168
Monitoring	90	2.2	3.0	3,168

3.5 Phase I – Sampling and Analysis Plan

After the pathogen tests, sampling will begin in the replicate 50-foot soil columns, sampling the column feed for the parameters identified in Table 3-1. Sampling of the effluent from the soil columns for the same parameters will occur based on the anticipated travel time through the columns as identified with the tracer testing, such that the influent and effluent data are comparable. Sampling will occur at the frequency and duration specified in the table and is anticipated to occur in mid-December of 2017 to February of 2018. Sampling for emerging contaminants will begin toward the latter half of the sampling campaign to allow acclimation and accumulation of biomass within the column.

Similarly, sampling for the 1 month replicate columns will occur in the feed with time delayed sampling at the outlet based on anticipated travel time. Refer to Table 3-1 for sampling frequency and duration.

Dissolved oxygen probes will be installed near the outlets of each set of column to collect continuous DO measurements. The probes will also record temperature readings of the effluents. Temperature sensor will be installed on the soil column frame to monitor ambient temperature.

Samples of the column media will be submitted to Virginia Tech for solid phase TOC analysis and a microbial community analysis. In order to account for the naturally occurring, temporal changes in the microbial community, two control reactors were set up (Figure 3-5); each one receiving pilot feed without free chlorine/monochloramine for the entirety of the study. The two reactors are being run in series, with the first reactor (2 inches in diameter and 3.5 feet high) simulating a travel time of 3.2 days and the second reactor (4 inches in diameter and 7 feet 8 inches high) simulating a travel time of 30 days. The plan was to take triplicate samples of the sand at three different stages. Media samples have been taken from the washed and sieved sand pile before placing in the columns and then from the column tops and the control columns after flushing. Media samples will finally be taken from different heights of the columns and the controls at the end of Phase I. Sterile centrifuge tubes were used for sampling and collection. Each sample was no less than 5 g and the amount sampled was kept consistent in mass volume across samples. Furthermore, a core sample from the aquifer will also be extracted for an overall comparison of the microbial communities.

Table 3-3. Duration, flow rates and pore volumes required for tests in control reactors

Experimental Phase	Duration (days)	Q (mL/min)	Pore volume (control for 50 feet)	Pore volume (control for 1 month)
Flushing	40	0.49	12.1	1.38
Monitoring	170	0.16	51.5	5.9

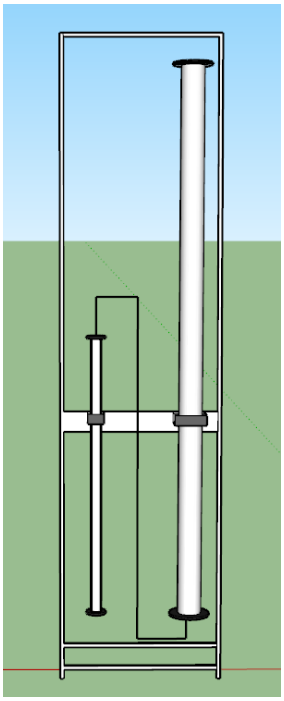


Figure 3-5: Control Reactors

As described above, considerable pathogen removal is anticipated through SAT. In order to confirm the pathogen removal credit available through SAT, MS2, *E.coli* and *Cryptosporidium* challenge tests were conducted using the 50-foot and 1-month travel time columns. For this purpose, the column feeds were spiked with MS2 sufficient to demonstrate > 6-log virus removal, *E.coli* sufficient to demonstrate >5 log removal and fluorescent microspheres (in lieu of *Cryptosporidium* oocysts) sufficient to demonstrate >

5-log removal. *E. coli K-12* is the specific strain that was used for the challenge tests. E. coli and fluorescent microspheres were injected in the columns simultaneously.

MS2 were injected in both the 50-foot columns for 5 days followed by injection of microspheres and E. coli. For the 1 month columns, MS2 were injected in one of the columns while E. coli along with microspheres will be injected in another for the duration of 30 days.

Table 3-4. Concentrations of tracer, MS2 and microbeads

	50 feet	1 month
Tracer (Chloride)	500 mg/L as Cl^-	500 mg/L as Cl^-
MS2	10^7 pfu/mL	10^7 pfu/mL
Microbeads	$1.24*10^5$ count/mL	$1.35*10^5$ count/mL
E. coli	10^6 MPN/mL	10^6 MPN/mL

Note:
Cl = chloride
MPN = most probable number
pfu = plaque forming unit

Concentration data for various constituents will be used to analyze loss coefficients to a 1D reactive transport model. The equation will include sorption/desorption and biodegradation and decay terms. Microbial data will be modeled using a particle-transport model that accounts for sorption, straining, and growth/decay dynamics.

Table 3-5. Sampling parameters for replicate soil columns.
Sampling to occur in the feed and the effluent.

Parameter	Method	Sampling Frequency	Duration	Anticipated Timeframe
50-foot column				
Ammonia (NH_3)	Lachat 10-107-06-1-C	3x/week	2 months	Dec-Feb
TKN	Lachat 10-107-06-2-I	3x/week	2 months	Dec-Feb
Nitrate (NO_3)	Calculation	3x/week	2 months	Dec-Feb
Nitrite (NO_2)	Lachat 10-107-04-1-C	3x/week	2 months	Dec-Feb
Nitrous Oxide		3x/week	2 months	Dec-Feb
Dissolved Organic Carbon	SM 5310 B-2011	3x/week	2 months	Dec-Feb
TOC	SM 5310 B-2011	3x/week	2 months	Dec-Feb
Disinfection Byproducts (HAA5)	EPA 552.2	3x/week	2 months	Dec-Feb
Total Trihalomethanes	EPA 624	3x/week	2 months	Dec-Feb
Orthophosphate	Lachat 10-115-01-1-A	3x/week	2 months	Dec-Feb
Total Phosphorus	Lachat 10-115-01-1-E	3x/week	2 months	Dec-Feb
Indicator CECs[1]	Varied	2x/week	3 weeks	Dec-Feb
Additional CECs[2]	Varied	1x/week	3 weeks	Dec-Feb
1 month column				
NH_3	Lachat 10-107-06-1-C	1x/week	3 months	Jan- Mar
TKN	Lachat 10-107-06-2-I	1x/week	3 months	Jan- Mar
Nitrate	Calculation	1x/week	3 months	Jan- Mar
NO_2	Lachat 10-107-04-1-C	1x/week	3 months	Jan- Mar
Dissolved Organic Carbon	SM 5310 B-2011	1x/week	3 months	Jan- Mar

Parameter	Method	Sampling Frequency	Duration	Anticipated Timeframe
TOC	SM 5310 B-2011	1x/week	3 months	Jan- Mar
Disinfection Byproducts (HAA5)	EPA 552.2	1x/week	3 months	Jan- Mar
Total Trihalomethanes	EPA 624	1x/week	3 months	Jan- Mar
Orthophosphate	Lachat 10-115-01-1-A	1x/week	3 months	Jan- Mar
Total Phosphorus	Lachat 10-115-01-1-E	1x/week	3 months	Jan- Mar
Indicator CECs[1]	Varied	2x/month	2 months	Jan-Feb
Additional CECs[2]	Varied	1x/month	2 months	Jan-Feb

[1] Refer to Table 7-2 in Attachment B for detailed list
[2] Identified in Table 3-6 of this Attachment
Notes:
EPA = U.S. Environmental Protection Agency
HAA5 = haloacetic acids (monochloroacetic, dichloroacetic, trichloroacetic, monobromoacetic, and dibromoacetic)
TKN = total kjeldahl nitrogen

Table 3-6.
Identification of individual CECs included in the soil column sampling and analysis plan.

Additional CECs	Rationale for Monitoring
Cyanotoxins	
Total microcystin	CCL4
Anatoxin-a	CCL3/CCL4
Cylindrospermopsin	CCL3/CCL4
Microcystin-LR	CCL3/CCL4
Disinfection Byproducts	
Chlorate	CCL4
Bromochloroacetic acid	UCMR4
Bromodichloroacetic acid	UCMR4
Dibromochloroacetic acid	UCMR4
Tribromoacetic acid	UCMR4
Flame Retardants	
BDE-100	Chemical of interest
BDE-153	Chemical of interest
BDE-154	Chemical of interest
BDE-183	Chemical of interest
BDE-209	Chemical of interest
BDE-28	Chemical of interest
BDE-47	Chemical of interest
BDE-99	Chemical of interest
Bromochloromethane	CCL3/CCL4/UCMR3
Bromomethane	CCL3/CCL4/UCMR3
Tris(2-chloroethyl) phosphate (TCPP)	Chemical of interest
Tris(1,3-dichloro-2-propyl)phosphate (TDCPP)	Chemical of interest

Additional CECs	Rationale for Monitoring
Hormone, Natural or Synthetic	
16-α-hydroxyestradiol (estriol)	CCL3/CCL4/UCMR3
17-α-ethynylestradiol	CCL3/CCL4/UCMR3
17-β-estradiol	CCL3/CCL4/UCMR3
4-androstene -3,17-dione	UCMR3
Androstenedione	Chemical of interest
Equilin	CCL3/CCL4/UCMR3
Estradiol	Chemical of interest
Estriol	Chemical of interest
Norethindrone	CCL3/CCL4
Progesterone	Chemical of interest
Testosterone	UCMR3
Pharmaceutical/Personal Care/Food derivatives	
Theobromine	Chemical of interest
1,7-Dimethylxanthine	Chemical of interest
Acesulfame-K	Chemical of interest
Butylparaben	Chemical of interest
Caffeine	Chemical of interest
Ethylparaben	Chemical of interest
Isobutylparaben	Chemical of interest
Methylparaben	Chemical of interest
Musk Ketone	Chemical of interest
Propylparaben	Chemical of interest
Triclocarban (TCC)	Chemical of interest
Acetaminophen	Chemical of interest
Albuterol	Chemical of interest
Amoxicillin	Chemical of interest
Atenolol	Chemical of interest
Azithromycin	Chemical of interest
Bendroflumethiazide	Chemical of interest
Bezafibrate	Chemical of interest
Butalbital	Chemical of interest
Carbadox	Chemical of interest
Carisoprodol	Chemical of interest
Chloramphenicol	Chemical of interest
Cimetidine	Chemical of interest
Clofibric Acid	Chemical of interest
Dehydronifedipine	Chemical of interest
Diazepam	Chemical of interest
Diclofenac	Chemical of interest
Dilantin	Chemical of interest
Diltiazem	Chemical of interest
Erythromycin	CCL3/CCL4
Flumequine	Chemical of interest

Additional CECs	Rationale for Monitoring
Fluoxetine	Chemical of interest
Galaxolide	Chemical of interest
Gemfibrozil	Chemical of interest
Ibuprofen	Chemical of interest
Iohexol	Chemical of interest
Iopromide	Chemical of interest
Ketoprofen	Chemical of interest
Ketorolac	Chemical of interest
Lidocaine	Chemical of interest
Lincomycin	Chemical of interest
Linuron	Chemical of interest
Lopressor	Chemical of interest
Meclofenamic Acid	Chemical of interest
Naproxen	Chemical of interest
Nifedipine	Chemical of interest
Oxolinic Acid	Chemical of interest
Pentoxifylline	Chemical of interest
Phenazone	Chemical of interest
Propazine	Chemical of interest
Quinoline	CCL3/CCL4/UCMR4
Sulfachloropyridazine	Chemical of interest
Sulfadiazine	Chemical of interest
Sulfadimethoxine	Chemical of interest
Sulfamerazine	Chemical of interest
Sulfamethazine	Chemical of interest
Sulfamethizole	Chemical of interest
Sulfamethoxazole	Chemical of interest
Sulfathiazole	Chemical of interest
Theophylline	Chemical of interest
Thiabendazole	Chemical of interest
Trimethoprim	Chemical of interest
Warfarin	Chemical of interest
Perfluorinated Compounds	
Perfluorobutanesulfonic Acid (PFBS)	UCMR3
Perfluoroheptanoic Acid (PFHpA)	UCMR3
Perfluorohexanesulfonic Acid (PFHxS)	UCMR3
Perfluoroocnanoic Acid (PFNA)	UCMR3
Perfluorooctanesulfonic Acid (PFOS)	CCL3/CCL4/UCMR3
Perfluorooctanoic Acid (PFOA)	CCL3/CCL4/UCMR3
Pesticides	
3-Hydroxycarbofuran	CCL3/CCL4
Bifenthrin	Chemical of interest
Bromacil	Chemical of interest
Chloridazon	Chemical of interest

Additional CECs	Rationale for Monitoring
Chlorotoluron	Chemical of interest
Chlorpyrifos	CCL4
cis-Permethrin	UCMR4
Cyanazine	Chemical of interest
Diaminochloro-atrazine (DACT)	Chemical of interest
Desethyl-atrazine (DEA)	Chemical of interest
Desisopropyl-atrazine (DIA)	Chemical of interest
Dimethoate	CCL3
Disulfoton	CCL3
Diuron	CCL3/CCL4
Fenitrothion	Chemical of interest
Fipronil	Chemical of interest
Isoproturon	Chemical of interest
Kepone	Chemical of interest
Metazachlor	Chemical of interest
Sulfometuron, methyl	Chemical of interest
Permethrins, Total (cis-, trans-)	UCMR4
Picloram	Chemical of interest
Tributyltin (nanograms per liter)	Chemical of interest
Semivolatile Organics	
4-nonylphenol - semi quantitative	CCL4
4-tert-octylphenol	CCL4
Aniline	CCL3/CCL4
Bisphenol A	Chemical of interest
Nitrobenzene	CCL3/CCL4
n-Nitrosodiethylamine	CCL3/CCL4
n-Nitrosodi-n-propylamine	CCL3/CCL4
n-Nitrosodiphenylamine	CCL3/CCL4
n-Nitrosopyrrolidine	CCL3/CCL4
Nonylphenol	CCL4
Propylbenzene	CCL3/CCL4
Volatile Organics	
1,1,1,2-Tetrachloroethane	CCL3/CCL4
1,1-Dichloroethane	CCL3/CCL4/UCMR3
1,2,3-Trichloropropane	CCL3/CCL4/UCMR3
1,3-butadiene	CCL3/CCL4/UCMR3
Acrolein	CCL3/CCL4
Chlorodifluoromethane (HCFC-22)	UCMR3
Chloromethane	CCL3/CCL4/UCMR3
Formaldehyde	CCL3/CCL4
Hexane	CCL3/CCL4
Methanol	CCL3/CCL4
Methyl tert-Butyl Ether	CCL3/CCL4
sec-Butylbenzene	CCL3/CCL4

Additional CECs	Rationale for Monitoring
Other	
Bromide	UCMR4
Cobalt	CCL4
Germanium	CCL4/UCMR4
Molybdenum	CCL4
Tellurium	CCL4
Vanadium	CCL4

BDE = brominated diphenyl ether
CCL = Candidate Contaminant List
UCMR = Unregulated Contaminant Monitoring Rule

3.6 Phase II Planning – SWIFTRC Soil Column Testing

The SWIFTRC is expected to commence operations in late January 2018. During initial operation, SWIFT Water will be recirculated to Nansemond Treatment Plant and ultimately discharged through the plant outfall. Once sufficient operational time has elapsed to allow HRSD to confirm the function of the SWIFTRC mechanical systems, instrumentation and controls, and SWIFT Water quality, MAR will commence using the SWIFTRC Recharge Well (TW-1) at flow rates increasing to 1 mgd.

As indicated above, the results of Phase I soil column testing work will be used in an adaptive management approach to guide the development of Phase II. The Phase II SAT testing program will likely be primarily focused on demonstration of fate of SWIFT Water constituents and microbial surrogates for travel times in excess of those investigated during Phase I (i.e. greater than 1 month), but work from Phase I will also be repeated using SWIFT Water from the SWIFTRC. Longer SAT retention times will be monitored in-situ throughout the demonstration period at wells MW-UPA, MW-MPA and MW-LPA, located 400, 450 and 500 feet from TW-1, respectively. For example, injectate water is expected to reach the monitoring wells between 6-12 months after commencement of recharge operations. However, as with Phase I, ex-situ testing in soil columns will allow additional data collection on temporal changes in injectate constituents during SAT and will allow investigation of removal of spiked microbial contaminant surrogates and perhaps also a cocktail of various organic chemicals of interest.

Additional columns will be constructed and installed at the SWIFTRC for the purpose of Phase II SAT testing. The columns will be designed to replicate 6 months of SAT and possibly up to 18 months. Design details, including physical construction and instrumentation, will generally replicate that of the Phase I columns. The sampling and analysis plan outlined for the Phase I columns will largely be followed for Phase II with the exception of sample frequency (preliminary planned to be monthly) and testing duration.

SECTION 4

Field Scale Testing of SAT at SWIFT Research Center

The facilities associated with MAR activities involved with the field scale SAT at the SWIFTRC include the test recharge well (TW-1) and a multi-aquifer monitoring well (MW-SAT) located 50 feet away from TW-1 (Figure 4-1).

Figure 4-1. Map of TW-1, MW-SAT, MW-UPA, MW-MPA, and MW-LPA at Nansemond WWTP

In addition to MW-SAT, the SWIFT facility will include three conventional monitoring wells (MW-UPA, MW-MPA, and MW-LPA) lying at distances ranging between 400 and 500 feet from TW-1, each screening multiple sand intervals in the Upper, Middle and Lower zones of the Potomac aquifer, respectively. Because of their distances, travel time in the PAS, and multi-screen construction, sampling results from MW-UPA, MW-MPA, and MW-LPA are not anticipated to influence the SAT studies. However, data from these wells will help characterize the geochemical environment and the transport behavior of some solute in the PAS. Construction and sampling of the conventional monitoring wells is addressed in Attachment C of the UIC Inventory.

SWIFT Water will leave the SWIFTRC and be pumped to TW 1. To discriminate between monitoring the SWIFT advanced water treatment processes and monitoring the aquifer response to MAR, this plan describes water exiting the advanced water treatment facility as “SWIFT Water,”and describes water injected into TW-1 as “recharge water.” HRSD will possess the capability to measure field chemistry and collect samples of the SWIFT Water, native groundwater, and ultimately recharge water from MW-SAT in the pilot area within the SWIFTRC.

4.1 Test Injection and Multi-Aquifer Monitoring Well

This section describes test injection well (TW-1) and MW-SAT and their roles in the SAT field-scale study.

4.1.1 Managed Aquifer Recharge Well

The MAR well (TW 1) extends to 1,410 feet below grade (fbg) and features a 12-inch-diameter carbon steel casing and 380 feet of stainless steel, 0.04-inch slot, continuous wire wrap screen (Figure 4-2).

TW-1 screens the Upper (120 feet), Middle (125 feet), and upper portion of the Lower (135 feet) zones of the PAS. The static water level in TW-1 reflects combined heads from each aquifer and fluctuates around 95 fbg. Water levels measured from the isolated aquifer units during packer testing varied from 95 to 97 fbg.

TW 1 will be equipped with a pressure transducer to measure and record static, injection, and backflushing water levels during MAR operations. HRSD will collect a total of 4 background groundwater samples from TW-1 before starting MAR operations. Because TW-1 screens multiple sand intervals in the PAS, the sample will represent water mixed from multiple zones. HRSD will monitor the quality of the SWIFT Water inside the SWIFTRC, as discussed in Attachment B, SWIFT Research Center SWIFT Water Quality Targets.

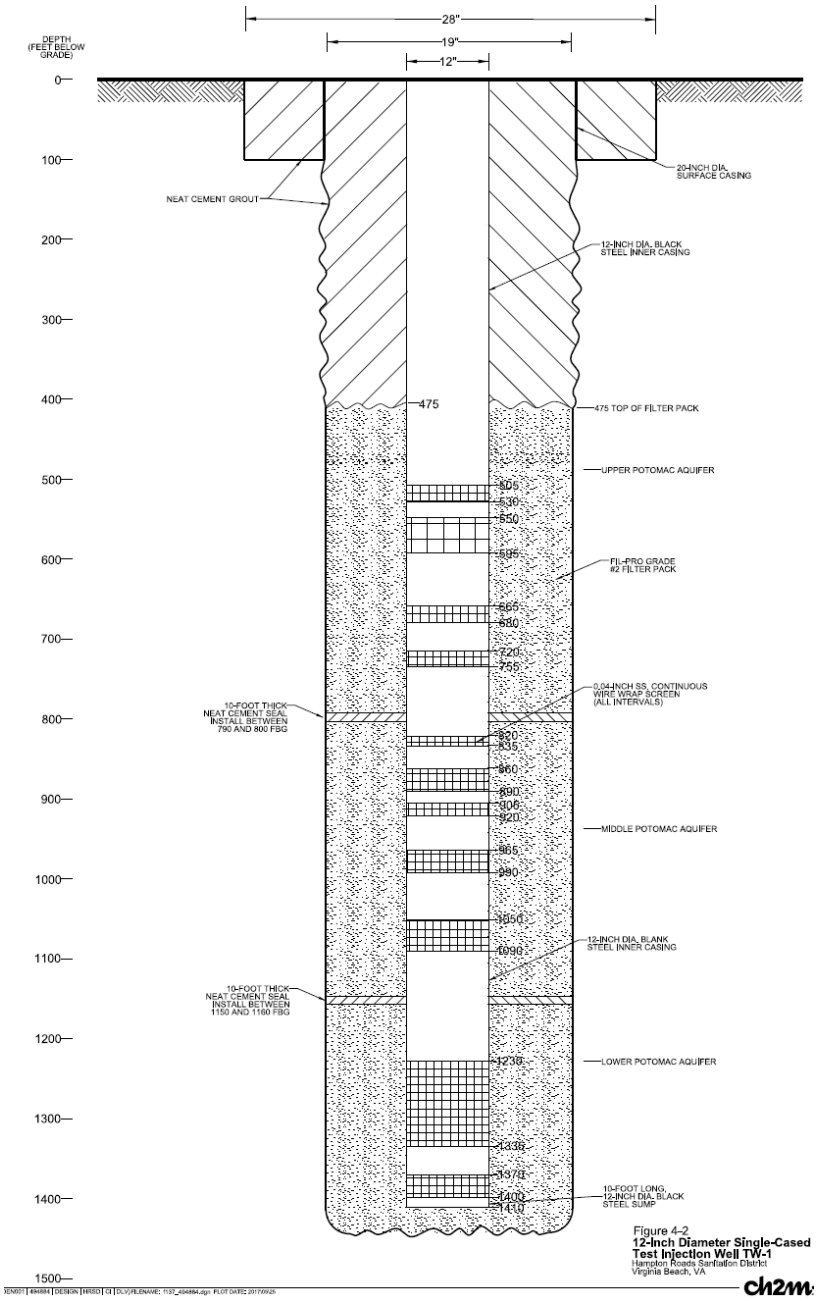


Figure 4-2. 12-inch Diameter Single-Cased Test Injection Well TW-1

4.1.2 Multi-Aquifer Monitoring Well (MW-SAT)

4.1.2.1 MW-SAT Well Construction

MW-SAT will lie approximately 50 feet from TW-1 and will support evaluating SAT in the PAS, in response to MAR operations at TW-1. MW-SAT will consist of a 6-inch-diameter carbon steel casing and 380 feet of stainless steel, continuous wire wrap screen extending to 1,410 fbg, the same depth as TW-1. The screen zones in MW-SAT will match the same intervals in TW-1 to the greatest extent practical.

4.1.2.2 MW-SAT FLUTe Sampling System

After installing and developing MW-SAT, a flexible liner, discrete-interval sampling system manufactured by FLUTe (Figure 4-3) will be installed in the casing and screen assembly.

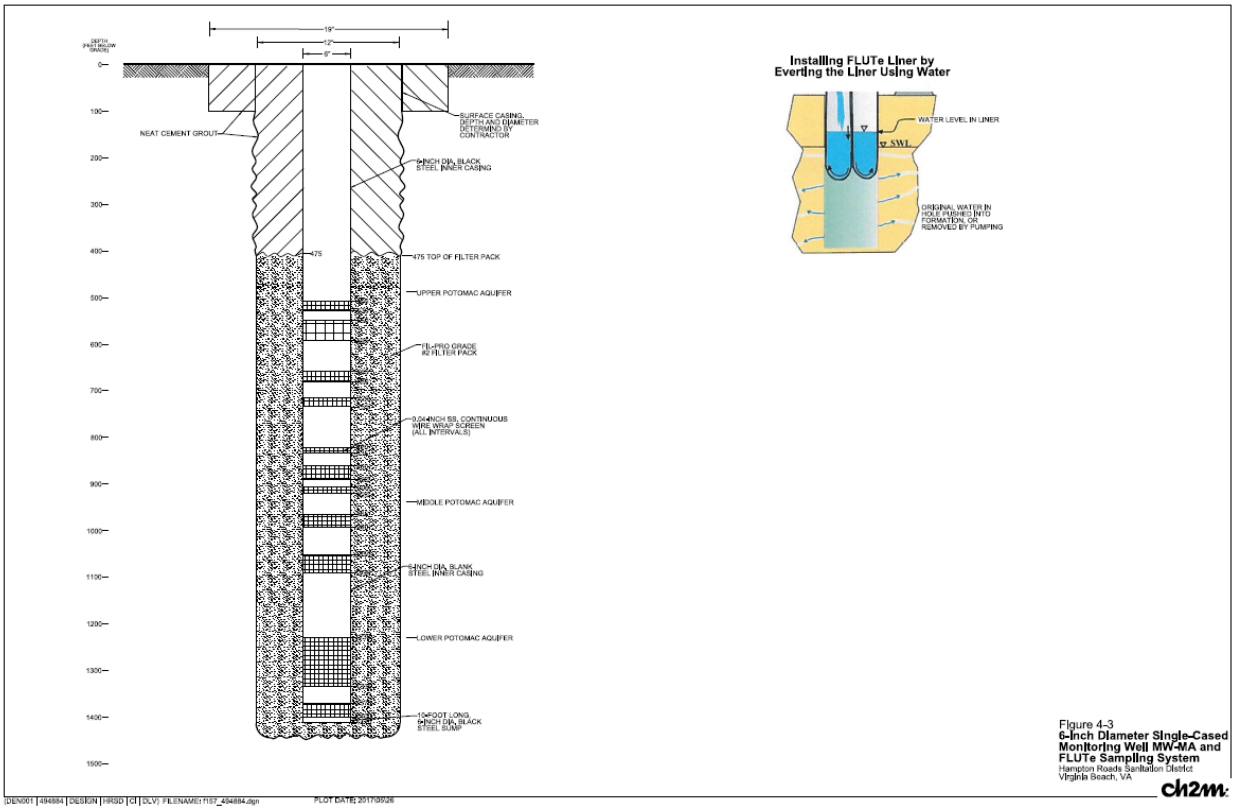


Figure 4-3. 6-inch Diameter Single-Cased Monitoring Well MW-MA and FLUTe Sampling System

The sampling system will consist of eleven sampling ports coinciding with each well screen. Sample tubing extending from each port will run to the ground surface and into the pilot area inside the SWIFTRC where HRSD can control purging, measure field chemistry and collect samples for laboratory analysis from the depth discrete intervals (Figure 4-4 Schematic of FLUTe system).

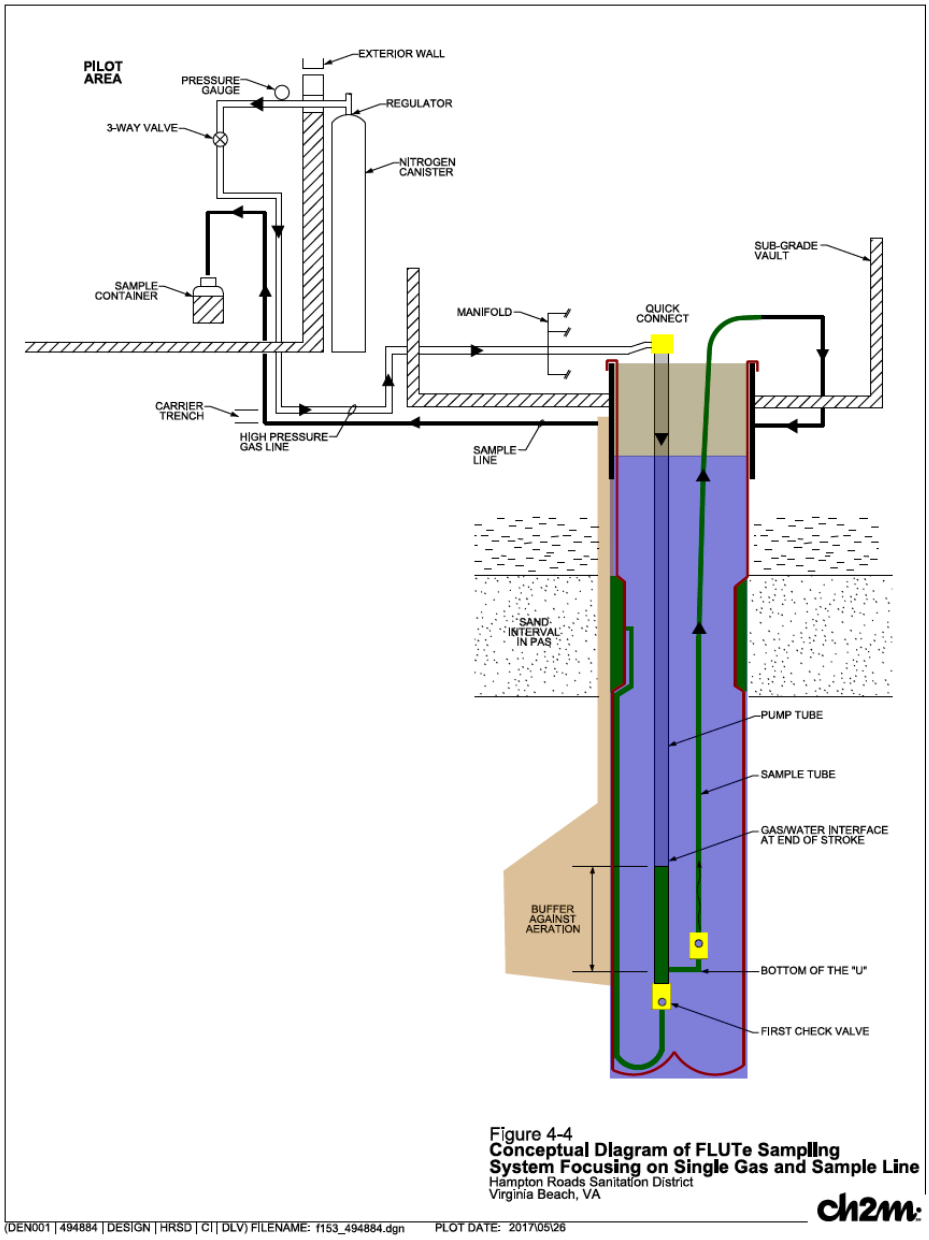


Figure 4-4. Conceptual Diagram of FLUTe Sampling System Focusing on Single Gas and Sample Line

Nitrogen gas from three canisters mounted on the exterior wall of the pilot area will drive sampling and purging. Operators will control purging and sampling from a three-way valve mounted on a panel in the pilot area (Figure 4-5 Panel diagram). To offer greater flexibility in selecting sampling intervals, three manifolds will segregate the gas-feed and sampling tubing by aquifer zone (UPA, MPA, and LPA zones). Recharge water may reach the deeper screens in TW-1 much later than the upper screens, and accordingly may not require the same sampling frequency.

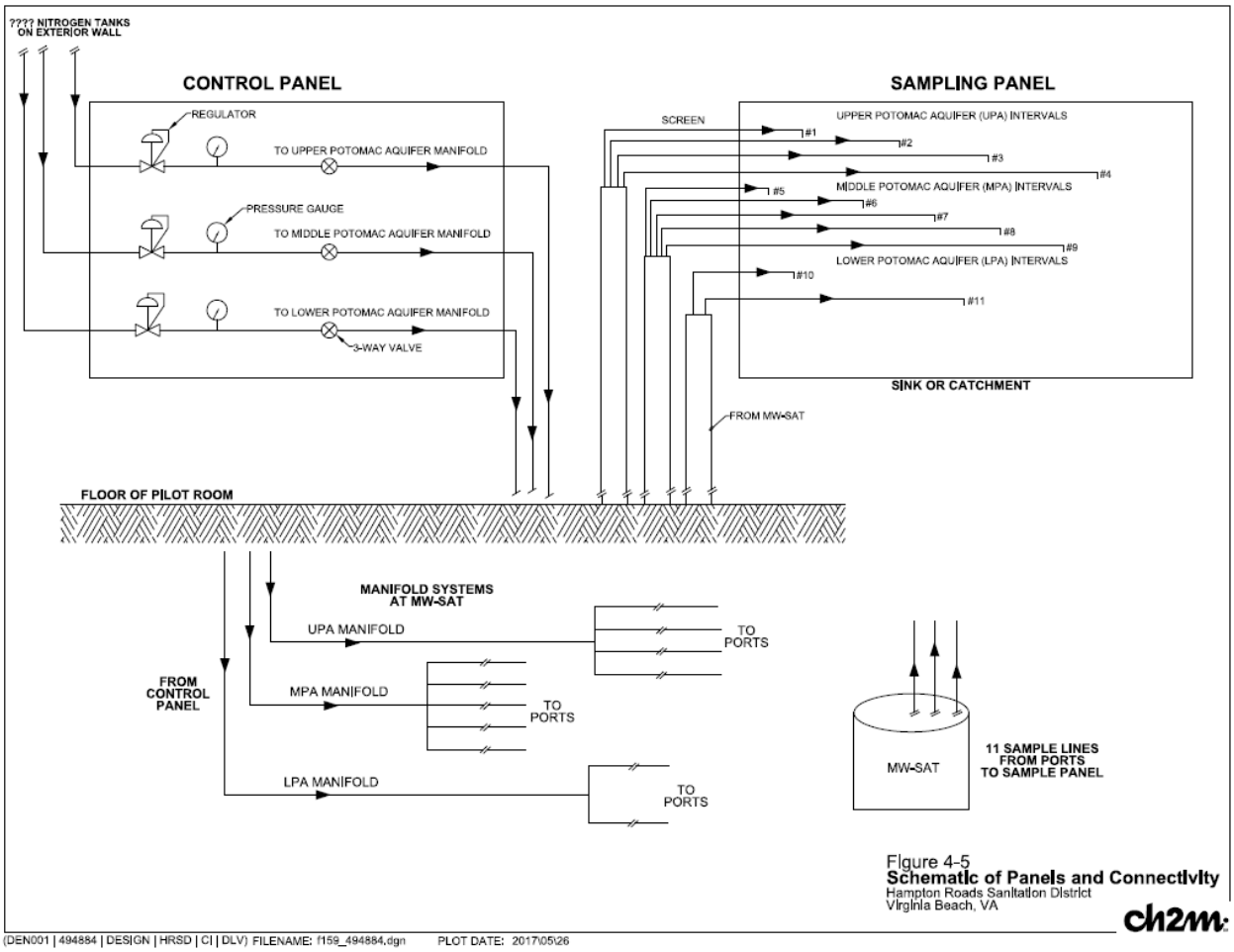


Figure 4-5. Schematic of Panels and Connectivity

MW-SAT will serve multiple, important roles in monitoring the geochemical response to MAR operations in the PAS. First, monitoring at MW-SAT will support characterizing hydrodynamic factors (advection, dispersion, mixing, etc.) influencing solute transport in the PAS, an important consideration for SAT. MW-SAT will also serve as a station to evaluate SAT of selected trace organic compounds including THMs, HAAs, CECs, NDMA, etc., along with the leaching of metals (iron, manganese, aluminum and arsenic) from reactive metal bearing minerals. Pathogens and pathogen indicators will not be monitored at MW-SAT, because it is almost certain that these will already be well below detectable levels in the SWIFTRC SWIFT Water, even with sampling of very large volumes of water. Pathogen removal by SAT must be assessed by challenge testing of the soil columns as described in Section 3.

4.2 Field Scale Monitoring Plan

The monitoring plan for evaluating SAT at the field scale includes monitoring SWIFT Water quality, native groundwater, and eventually recharge water migrating in the PAS.

4.2.1 SWIFTRC SWIFT Water

SWIFT Water will continually discharge into a sample sink in the SWIFTRC laboratory and will be continuously monitored by online analyzers for temperature, pH, turbidity, specific conductivity, and DO. Table 9 in Attachment B of the UIC Inventory details the samples and sample frequency identified

for demonstrating SWIFT Water regulatory compliance, treatment efficacy of trace contaminants, and important recharge water chemistry.

4.2.2 Multi-Aquifer Monitoring Well

MW-SAT, located only 50 feet from TW-1, will serve multiple roles in evaluating field scale SAT during MAR operations at the SWIFTRC including:

- Characterizing hydrodynamic elements (advection, dispersion, mechanical mixing etc.) of solute transport in the PAS system.
- Describing redox conditions at the interface between recharge and native groundwater.
- Helping determine the magnitude of cation exchange between the recharge and aquifer.
- Quantifying the attenuation and treatment/removal of major constituents in the recharge, including DO, nitrate, TKN, phosphorus, orthophosphate, TOC, DOC, chemical oxygen demand, and several others.
- Characterizing SAT of selected trace organic compounds such as THMs, HAAs, CECs, and NDMA.
- Monitoring the leaching of undesirable metals from minerals in the PAS including iron, manganese, and arsenic.

A total of 4 background samples will be collected from MW-SAT prior to recharge operations.

4.2.2.1 Tracer Selection

Tracer selection is discussed in detail in Attachment C, section 2.3.1 of this UIC Inventory. A tracer should be non-reactive between water types and minerals in the aquifer and significantly differing in concentration than native groundwater. Chloride fits these two criteria as a relatively inert ion, differs significantly in concentration between the recharge water (220 mg/L) and groundwater produced from the three aquifers (1,970 to 2,760 mg/L). Specific conductivity is not a direct measurement of the amount of chloride in the water, however, it is easy to measure and can be used to screen for chloride. Both specific conductivity and chloride will be measured and used to identify the recharge water front moving through the monitoring well.

4.2.2.2 Estimated Travel Time

Located only 50 feet away, recharge may reach at least some of the screen intervals in MW-SAT relatively rapidly. If recharge spreads evenly across the eleven screen intervals, totaling 380 feet in length, HRSD will need to recharge 5.8 million gallons before its arrives at MW-SAT (Table 4-1). Dividing the volume by the recharge rate (1 mgd) provides the time (5.8 days) for recharge to arrive at MW-SAT.

Table 4-1. Volumes and times for recharge to reach intervals in MW-SAT

Monitoring Well	Recharge Entering Well Screens	Without Dispersion Volume (mgd)	With Dispersion in Sand Aquifer Volume (mgd)
MW-SAT[1]	All screens[2]	5.8	2.1
	Top UPA Only[3]	0.4	0.14
	UPA Only[4]	2.1	0.8
	UPA and MPA[5]	3.9	1.5

Notes:

[1]MW-SAT located 50 feet away from TW-1

[2]All screen intervals in TW-1 total 385 feet

[3]Top screen in UPA equals 25 feet in length

[4]Screen length in UPA equals 140 feet

[5]Screen length in UPA and MPA equals 265 feet

Because recharge is assumed to spread evenly across the eleven screens, this duration represents the maximum time for recharge to reach MW-SAT. However, several factors can reduce the time for recharge to arrive at a monitoring point, including hydrodynamic dispersion (longitudinal dispersion in the aquifer, recharge channeling along higher permeability pathways, and density segregation. Considering dispersion, it is expected that recharge water will reach MW-SAT after approximately 2 million gallons, taking about 2 days.

During MAR operations, recharge water will more likely exit TW-1 through the uppermost screens and migrate preferentially through the UPA and portions of the MPA, before the LPA. Hypothetically, if all the recharge enters the uppermost screen interval in the UPA, which measures 25 feet in length, water could arrive at MW-SAT after only 0.14 days, if influenced by dispersion, or 0.4 days, if not.

4.2.2.3 Breakthrough Curve

Characterizing the relationship between advection and dispersion in each sand interval screened by MW-SAT using chloride as a tracer will establish a sound basis for evaluating groundwater and solute velocities. The curves will support evaluating the fate of constituents in the PAS other than chloride, including the attenuation of major ions, trace metals, nutrients, and trace organic components undergoing SAT (Figure 4-6). The concentration versus time relation at the monitoring point is often called the breakthrough curve. The geometry of the curve for an individual solute in relation to the tracer's curve can help an analyst interpret the attenuation experienced by the solute. HRSD will compare breakthrough curves for constituents sampled at MW-SAT and from samples exiting the soil columns.

An important factor in reducing transport data and interpreting breakthrough curves will involve knowing the exact linear distance between TW-1 and MW-SAT. Because of the depth of the wells, the distance may differ between shallow and deeper screen intervals, depending on the slope of each wellbore away from true plumb. The exact distances between the screen intervals in TW-1 and MW-SAT will be obtained using gyroscopic surveys conducted in the two wells used to estimate distances based on the slope in each.

4.2.2.4 Water Quality Monitoring

The FLUTe sampling system installed in MW-SAT will consist of polyvinylidene fluoride (PVFD) tubing running from a sample port situated in each well screen to the ground surface. PVFD tubing exhibits the same inert, chemical characteristics as Teflon, but is stronger and less likely to kink during installation or sampling operations. Collection of rinseate samples through PVFD tubing conducted by FLUTe has yielded less than method detection limits for all CEC constituents.

Sampling personnel will employ a nitrogen source to purge the tubing and then withdraw samples from each interval. The use of nitrogen prevents aeration and the alteration of redox in a sample. The pumping system accommodates filling sample bottles quickly and efficiently. The system will also allow attachment of tubing for connection to a flow-through cell to measure important field chemistry constituents (temperature, pH, specific conductivity, ORP, and DO). The 11 sampling tubes will be piped to a sample sink in the piloting area of SWIFTRC.

Groundwater samples will be collected from each of the eleven ports installed in the center of the screen intervals, prior to starting MAR operations. Monitoring the recharge as it first flows past MW-SAT

in each affected screen interval represents a critical element in discriminating between advective and dispersive transport of a solute in the PAS. Accordingly, samples collected must capture the change in water chemistry as recharge water displaces groundwater in the sand beds of the PAS. This monitoring will require recording specific conductivity measurements, and analyzing chloride in the field using titrators every 12 hours after MAR operations commence at 1 mgd.

Once recharge is detected in a specific interval using specific conductivity and chloride, operators should plan on collecting samples for a more comprehensive suite of analytes at 12 hour intervals in the uppermost screen intervals of MW-SAT. Specific conductivity and chloride measurements collected at 24 hour intervals should continue in deeper screens until measurable changes in water chemistry are encountered. At a minimum, all regulatory limit parameters and performance indicators should be measured on a consistent basis. These parameters are identified in Attachment C of this UIC Inventory.

Once specific conductivity, chloride, calcium, sodium, magnesium, potassium (cations), sulfate, alkalinity (anions), iron, manganese, aluminum (trace metals), nitrate, TKN, nitrite, total phosphorous, ortho-phosphate as P (nutrients), TOC/DOC, and total dissolved solids (TDS) in samples from a sand interval in MW-SAT equal the concentrations observed in samples from the SWIFT Water, or are stable after 3 samples, operators can reduce the sampling frequency for these constituents, and the interval, to weekly for one month and then monthly, thereafter, with the exception of arsenic. Samples should continue to be collected and analyzed for arsenic on a weekly frequency over the duration of the project.

Daily monitoring for specific conductivity and chloride in deeper screen intervals should continue until concentrations change, indicating the presence of recharge water. Once recharge is detected, operators should collect samples for cations, anions, trace metals, nutrients, TOC/DOC, and TDS analysis on a daily basis. As concentrations of the constituents from the MW equal the concentrations in the SWIFT Water or are stable after three samples, sampling frequency can be reduced to monthly.

SECTION 5

Evaluating Column and Field Scale Testing Results

Column and field scale testing will produce an enormous amount of field measurements and laboratory analytical data. This section describes some of the techniques HRSD anticipates employing to reduce and then evaluate these data. To achieve uniformity in the evaluation, HRSD will coordinate the analysis of column and field scale testing data. Accordingly, analysis of the column and field scale testing studies are considered together in this section, with narrative differences in analytical approaches between the studies, as appropriate.

Many analytical techniques are described in recent literature on treating data from column and field scale testing studies. This section discusses a few of the more, obvious and rudimentary techniques. HRSD will update this plan, as the analysis grows and deviates from this plan as the data emerges from the study.

5.1 SAT Inventory and Breakthrough Tracking

A critical element of the column and field scale testing will involve accounting for parameters that exhibited full or partial breakthrough, and those that did not appear in samples collected during the testing. Many CECs will attenuate during transport through the columns or the PAS over the finite testing duration. Conversely, most of the field chemistry parameters, cations, anions, trace metals, and nutrients should achieve partial to full breakthrough in at least the shallower sample ports of MW-SAT. The number of sand intervals and the changing hydraulic regime in TW-1, as injection heads change or the well clogs will complicate the evaluation of some results, particularly trace organics.

HRSD will need to account for the constituents achieving breakthrough, and those that fail to appear in samples that exit the columns or the sample ports from MW-SAT. In developing the inventory, HRSD can characterize pathogen (soil column only), or organics removal for constituents that did not exit the column or appear in samples collected from the sample ports at MW-SAT.

5.2 Characterizing the hydrodynamic signature

A simple evaluation of breakthrough will involve plotting constituent concentrations (Ct) recovered at a column or sample port divided by the starting concentration (Co) on the Y-axis against time (X-axis). The plot will allow characterizing amount of breakthrough exhibited by the constituent. A partial or complete breakthrough curve should accommodate characterizing how hydrodynamic factors influence the transport of constituent. This evaluation forms an important starting point for describing mechanisms that attenuated the constituent during migration through the column or PAS.

5.3 Defining the Geochemical Environment

An important intermediate step in characterizing constituent attenuation entails characterizing the geochemical environment of the columns or discrete sand intervals in the PAS. Geochemical indicators include pH, bulk water chemistry, ionic strength, redox, and TOC/DOC content. Several tools are available to address these factors. An analyst should develop a Piper diagram (Figure 5-1) of the ionic water chemistry, calculate the ionic strength using simple analytical techniques or geochemical modeling, and characterize redox by plotting averaged ORP measurements on an Eh diagram (Figure 5-2). A new analytical method developed by the United States Geological Survey (Jurgens et al., 2009)

considers common redox indicators beyond ORP (DO, nitrate, manganese, iron, sulfate, sulfide) to describe the redox environment.

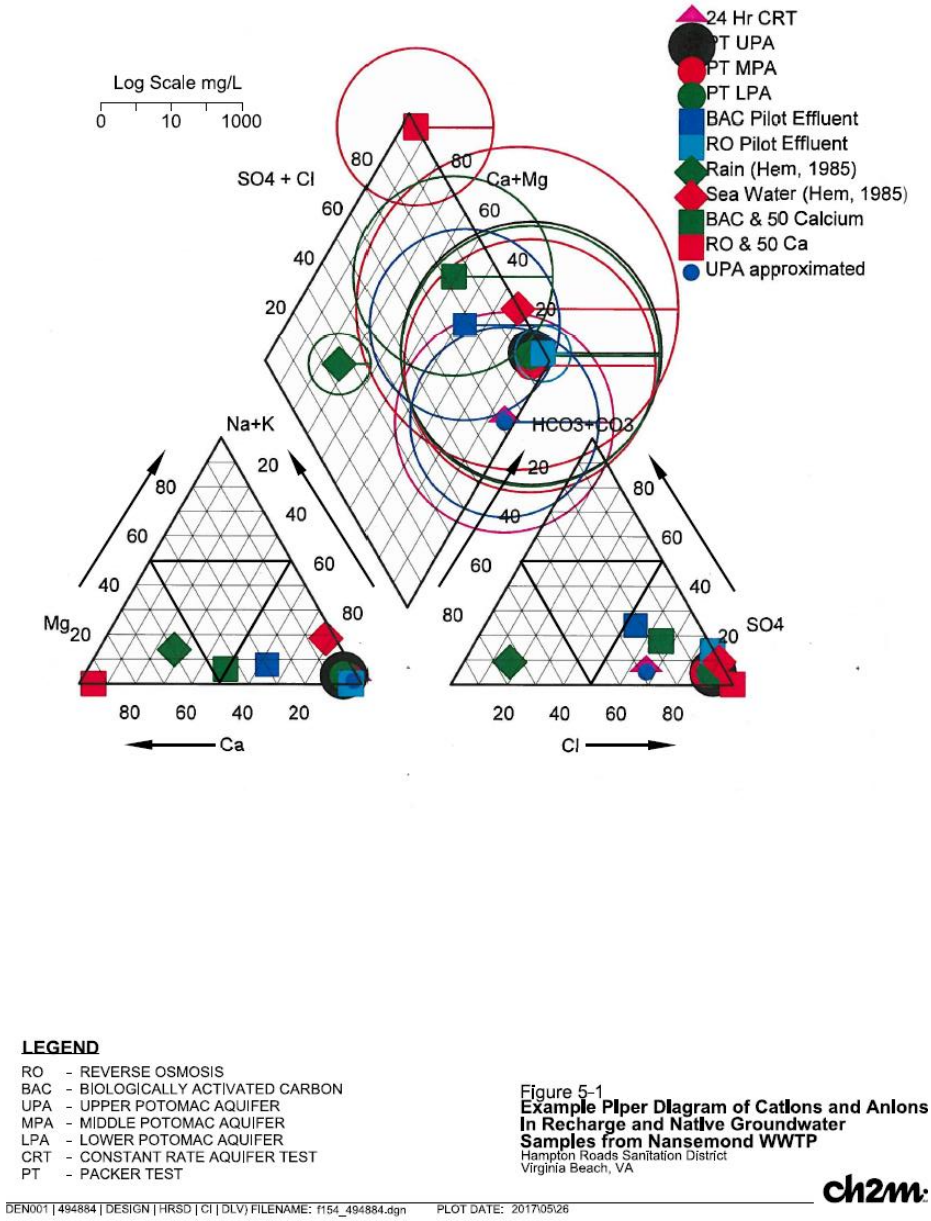


Figure 5-1. Example Piper Diagram of Cations and Anlons In Recharge and Native Groundwater Samples from Nansemond WWTP

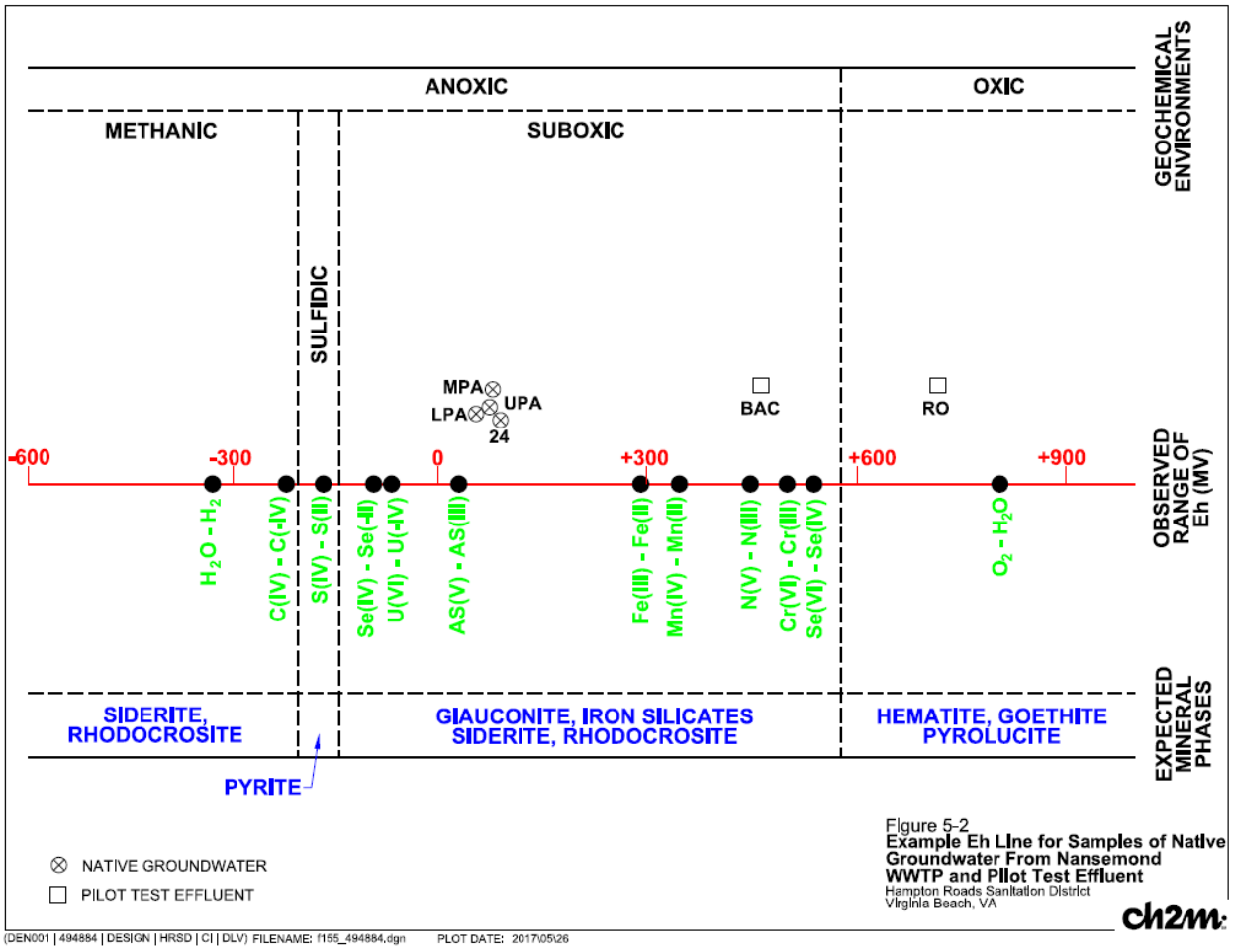


Figure 5-2. Example Eh Line for Samples of Native Groundwater From Nansemond WWTP and Pilot Test Effluent

5.4 Evaluate Attenuation Mechanisms

Identifying attenuation mechanisms for an individual constituent can represent the most challenging aspect of evaluating column or field scale data. HRSD should evaluate attenuation mechanisms for constituents exhibiting a partial to full breakthrough curve. The assessment of the breakthrough curve should include a working knowledge of the geochemical environment, displayed in the column or sand interval of the PAS. Evaluating attenuation mechanisms for individual constituents will also require reviewing available literature describing similar studies.

5.5 Solute Transport and/or Geochemical Modeling

Solute transport, reactive transport, and geochemical equilibrium models provide powerful tools for evaluating the migration of constituents in groundwater. They achieve their greatest level of effectiveness with accurate input data, and the analysts' understanding of the geochemical environment undergoing modeling. The models are most often used to mathematically simulate the transport of a constituent in a column or an aquifer. Important input parameters are modified to duplicate the column or field scale results (calibration). Once a model is calibrated and verified, simulations are run to predict the migration of a constituent under differing conditions, or to extend the time scale beyond the duration of a column or field scale experiment.

Solute transport models like MT3D (Zhang, 1990), MOC (Konikow et al., 1978), SUTRA (Voss et al., 2004), etc. use mathematical coefficients to represent hydrodynamic (advection, dispersion, and diffusion), solute decay, and chemical reactions. Single numerical terms representing complex environmental reactions are used as input to a solute transport model. Solute transport models allow simulating system in one, two, and three dimensions. They represent the most popular tools for simulating constituent transport in a column.

By comparison, geochemical models like MINTEQA2 (Allison, et. Al., 1991), PHREEQC (Parkhurst, 1995), and the Geochemist's Workbench (Bethke, 1996) use water chemistry, mineral phases, temperature, and the partial pressures of gas as input to simulate mineral speciation and solubility, surface complexation, mass transfer/reaction path, and inverse reactions in a beaker. Solute transport is often simulated in one dimension as migration along a line from a source. PHREEQC allows simulating differing geochemical environments along a linear flowpath, and reversing the direction of flow.

SECTION 6

Deploying the Testing Results

This section describes applying the results and conclusions from the column and field scale SAT testing to assess groundwater quality, analyze risk to local groundwater users, and how to apply the results to obtain regulatory benefits for an advanced wastewater treatment facility. At this stage of the project, these topics seem highly speculative and will require revision as testing proceeds at SWIFTRC.

6.1 Assessing the Influence of Managed Aquifer Recharge Operations on Groundwater Quality

At the end of column and field scale testing, HRSD will possess significant amounts of data that support determining how MAR operations will influence groundwater quality in the PAS. Where the monitoring described in Attachment C will focus on cations, anions, trace metals, and other general water quality parameters, this assessment will focus on constituents inherent with advanced treatment of wastewater including pathogens, TOC/DOC, nitrogen species, CECs and NDMA.

6.2 Analysis of Risk to Local Receptors

One application of the column and field scale testing should involve simulating the migration of a constituent(s) that exhibited breakthrough during testing, toward the closest receptors using groundwater from the PAS. Receptors could include large (municipal, industrial, agricultural, etc.) and small scale users (domestic) to assess a constituent migration under ambient and strong pumping gradients. This type of analysis should include conservative simulations, involving only advective transport (particle tracking), in combination with simulations comprising the geochemical and/or biological factors that attenuate constituents during migration. If testing demonstrates, that SAT removes or acceptably attenuates the constituents of interest, HRSD may not require these analyses.

SECTION 7

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